Cunninghamia

A journal of plant ecology for eastern Australia

Botanic Gardens Trust
SYDNEY

Volume 11(3)
2010

Cunninghamia

A journal of plant ecology for eastern Australia

***Cunninghamia*: a journal of plant ecology for eastern Australia** publishes original research papers on all aspects of plant ecology with particular emphasis on the vegetation and flora of eastern Australia. Descriptive, experimental and historical studies of plant communities, populations, individuals, their interactions with other organisms and their management are acceptable. Acceptance is the responsibility of an editorial committee chaired by the Scientific Editor. All papers are peer-reviewed.

Cunninghamia is published twice a year by the Botanic Gardens Trust.

Annual Subscription rates for 2010 (2 issues)

Within Australia		*Overseas*
Individuals	$77	A$105 (surface mail)
Institutions	$110	A$165 (surface mail)

For subscriptions please send a cheque made out to the ***Botanic Gardens Trust*** addressed to:

The Administrative Officer,
Mount Annan Botanic Garden,
Mount Annan Drive, Mount Annan 2567

Subscription enquiries phone (02) 4648 2477

Issues of ***Cunninghamia*** (including back issues) are available from the Gardens Shops at the Royal Botanic Gardens, Mount Annan Botanic Garden and Mount Tomah Botanic Garden. For phone enquiries contact the Gardens shop at Mount Annan Botanic Garden (02) 4634 7935.

Order forms for subscriptions and back issues can be printed from our website: www.rbgsyd.nsw.gov.au.

Allan Cunningham

Allan Cunningham, botanist and explorer (1791–1839)

Cover: Native vegetation of southeast New South Wales: clockwise from top left; Sandstone Headland Scrub, Royal National Park (photo M. Tozer); Castlereagh Scribbly Gum Woodland, Holsworthy (photo K. Turner); Riverbank Forest, Abercrombie River (photo K. Turner); South Coast Headland Scrub, Bittangabee (photo Jackie Miles); Estuarine Mangrove Forest, Narooma (photo Jackie Miles).

(for details see Tozer et al, this issue pages 359–406 and accompanying CD)

Cunninghamia

A journal of plant ecology for eastern Australia

Volume 11(3): 277–406 • 2010

SHORT COMMUNICATIONS

Whipcord plants: a comparison of south-eastern Australia with New Zealand
R.F. Parsons 277

Recent ecological observations on growth rates and seed production in *Isopogon prostratus* (Proteaceae), a little-known prostrate shrub from south-eastern NSW and Victoria
Doug Benson and Lotte von Richter 283

RESEARCH PAPERS

Waratah theft in Brisbane Water National Park - An analysis of the blue paint poaching reduction program
Doug Beckers and Catherine A. Offord 287

Coastal sandplain vegetation at Brisbane Water and Broken Bay - reconstructing the past to plan for the future
Robert Payne, Ross Wellington and Michael Somerville 295

Biomass and floristic patterns in the ground layer vegetation of box-gum grassy eucalypt woodland in Goorooyarroo and Mulligans Flat Nature Reserves, Australian Capital Territory.
S. McIntyre, J. Stol, J. Harvey, A. O. Nicholls, M. Campbell, A. Reid, A. D. Manning, and D. Lindenmayer 319

Native vegetation of southeast NSW: a revised classification and map for the coast and eastern tablelands
M.G. Tozer, K. Turner, D.A. Keith, D. Tindall, C. Pennay, C.Simpson, B. MacKenzie, P. Beukers and S. Cox 359

CD to accompany Tozer et al. inside backcover

***Cunninghamia* 11(3): 277–406 • July 2010**

Scientific Editor
Doug Benson
Royal Botanic Gardens,
Mrs Macquaries Road, Sydney, Australia 2000.
Email: doug.benson@rbgsyd.nsw.gov.au

Scientific Editorial Committee
Brett Summerell, John Benson, Bob Makinson,
Tony Auld.

Typesetting and Production
Julia Sideris

Printer
Finsbury Green

ISSN 0727-9620
© 2010 Botanic Gardens Trust
Royal Botanic Gardens, Mrs Macquaries Rd,
Sydney, Australia 2000.

www. rbgsyd.nsw.gov.au
www.rbgsyd.nsw.gov.au/science/Scientific_publications/cunninghamia

Whipcord plants: a comparison of south-eastern Australia with New Zealand

R.F. Parsons

Department of Botany, La Trobe University, Bundoora, VIC 3086, AUSTRALIA Email: r.parsons@latrobe.edu.au

Abstract: Whipcord plant is a term used for some dicot angiosperms with small, scale-like leaves closely appressed to the stem. So far, the term has mostly been used in this sense for plants from New Zealand. Here, I summarize the incidence and habitat relations of New Zealand whipcord plants and then use the literature to show that whipcord plants also occur in south-eastern Australia. New Zealand whipcord plants comprise nine species of *Hebe*, four of *Leonohebe* and six of *Helichrysum*, while in south-eastern Australia there are six species of *Ozothamnus* and one of *Leucophyta*. In both areas, some species are alpine to subalpine, while some are from lowland habitats with significant summer water deficits.

Cunninghamia **(2010) 11(3): 277–281**

Introduction

Since at least the publication of Cockayne (1928), the term whipcord plant has been used in the botanical literature for dicot angiosperms with small, scale-like leaves closely appressed to the stem, giving the shoots a cord-like appearance. The term has been used most for groups of New Zealand species within *Hebe* and *Helichrysum* (Wardle 1991). However, it is clear that the term whipcord is synonymous with the term cupressoid, the same morphology being common in the gymnosperm families Cupressaceae (e.g. *Libocedrus*) and Podocarpaceae (e.g. *Dacrydium*, *Halocarpus*) (Cockayne 1928, Wardle 1991). In fact, when the two cohabit, the whipcord *Hebe armstrongii* is almost indistinguishable from the podocarp *Halocarpus bidwillii* except when it is flowering (Wardle 1991).

As far as I know, the term whipcord has not been applied to angiosperms other than those from New Zealand except for some species of the Northern Hemisphere genus *Cassiope* (Ericaceae) (Huxley 1999; dealt with more fully below). For gymnosperms, it is widely used for a form of the North American western red cedar (*Thuja plicata*, Cupressaceae; Google search of 'whipcord', 2009). In this note, I start by summarizing the incidence and habitat relations of whipcord plants in the New Zealand angiosperm flora. I then document the occurrence of native whipcord angiosperms in south-eastern Australia and compare their habitat relations with the New Zealand data. The analogous cupressoid life form of some gymnosperms is not dealt with further.

Methods

The data were compiled solely from literature searches for angiosperm species with small, scale-like leaves closely appressed to the stem in adult plants. In young plants of whipcord species, it is common for the leaves to be more or less divergent from the stem (Cockayne 1928, Eagle 2006).

Species nomenclature follows http://nzflora.landcareresearch.co.nz (2009) (New Zealand) and Harden (1992), Puttock (1999) and Buchanan (2009) (Australia) unless specified. I am aware that some workers now include *Hebe* and *Leonohebe* within *Veronica* (e.g. Mabberley 2008). This is discussed more fully by Bayley & Kellow (2006).

I follow de Lange & Norton (2009) in including the penalpine and nival altitudinal zones of Wardle (1991) within the term alpine. The Australian term 'mallee' refers to vegetation dominated by multi-stemmed, tall shrub species of eucalypts, usually found in semi-arid areas drier than eucalypt woodland.

© 2010 Botanic Gardens Trust

Table 1. New Zealand whipcord plants: leaf length of adult plants and habitat

Data from Allan (1961), Mark & Adams (1986), Wardle (1991), Widyatmoko & Norton (1997), Bayley & Kellow (2006), Eagle (2006). n.a. = not available

Family/species	Leaf length (mm)	Habitat
Plantaginaceae		
Hebe annulata	0.75 – 1	Subalpine
Hebe armstrongii	1	Montane to subalpine
Hebe hectorii	1.2 – 3	Subalpine to alpine
Hebe imbricata	1 – 2	Subalpine to alpine
Hebe lycopodioides	1.5 – 2	Subalpine to alpine
Hebe ochracea	1 – 1.5	Alpine
Hebe propinqua	1 – 2	Subalpine to alpine
Hebe salicornioides	1 – 2	Subalpine to alpine
Hebe tetragona	1.5 – 3.5	Subalpine to alpine
Leonohebe cheesemanii	1	Alpine
Leonohebe cupressoides	1 – 1.5	Lowland to alpine
Leonohebe tetrasticha	1 – 1.5	Subalpine to alpine
Leonohebe tumida	1 – 1.5	Subalpine to alpine
Asteraceae		
Helichrysum coralloides	5	Montane to alpine
Helichrysum depressum	n.a.	Montane to alpine
Helichrysum dimorphum	1.5	Lowland
Helichrysum intermedium	2 – 4	Lowland to alpine
Helichrysum parvifolium	2	Montane to alpine
Helichrysum plumeum	2–4	Montane to alpine

Table 2. South-eastern Australian whipcord plants: leaf length of adult plants, distribution and habitat

Data from Curtis (1963), Harden (1992) and Puttock (1999). For distribution, NSW = New South Wales; Q = Queensland; SA = South Australia; T = Tasmania; V = Victoria

Family/species	Leaf length (mm)	Distribution	Habitat
Asteraceae			
Leucophyta brownii	1.5–14	SA, T, V	Exposed coasts
Ozothamnus adnatus	1–4	NSW, V	Dry forests and woodlands
Ozothamnus diotophyllus	2–5	NSW, Q	Mallee
Ozothamnus hookeri	1–2	T	Alpine
Ozothamnus pholidotus	1.5–4	SA, V	Mallee
Ozothamnus scutellifolius	0.4–1.5	T	Dry hillsides
Ozothamnus species 1	1.5–4	NSW, V	Subalpine to alpine

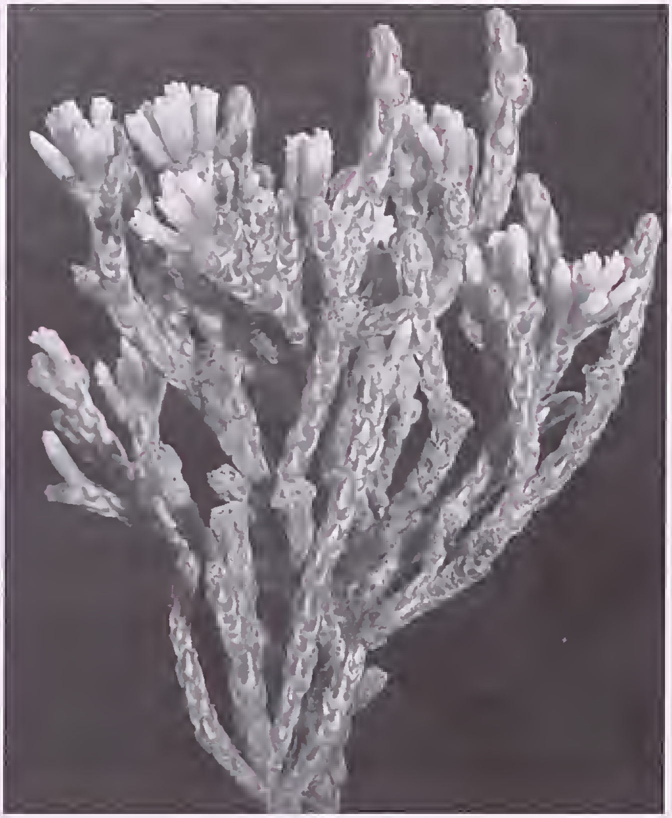


Fig. 1. Whipcord plant of *Ozothamnus hookeri*, Mt. Field, Tasmania. Photo by David Tng.

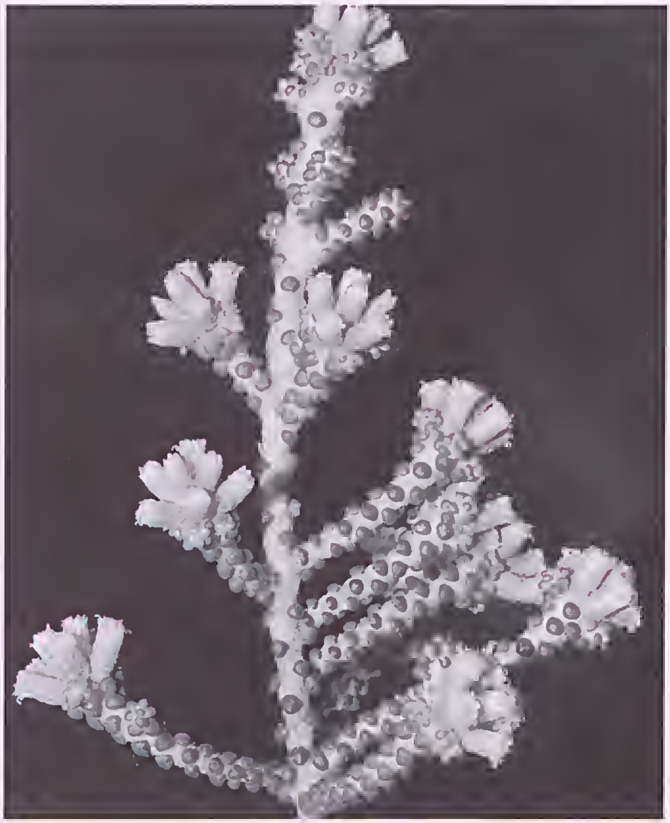


Fig. 2. Whipcord plant of *Ozothamnus scutellifolius*, Tasman Peninsula, south-east Tasmania. Photo by David Tng.

Results

New Zealand

All of the whipcord plants are in the genera *Hebe*, *Helichrysum* and *Leonohebe* (Table 1). Except for the liane *Helichrysum dimorphum* (see Allan 1961, Eagle 2006), all are shrubs. At least one is also a cushion plant (*Helichrysum coralloides*, Eagle 2006).

In selecting the whipcord species of *Hebe*, I have followed Bayley & Kellow (2006) in recognizing nine species (Table 1). In the genus *Leonohebe*, they describe the four species of Section *Leonohebe* as 'the Semiwhipcords'. Three of the four species obviously meet the definition of whipcord (see Table 1) but I have excluded *Leonohebe ciliolata* as its leaves clearly diverge from the stem (see the figures in Mark & Adams (1986), Bayley & Kellow (2006) and Eagle (2006)). The other Section, *Aromaticae*, consists solely of *Leonohebe cupressoides*. While it differs from the other whipcord species in having widely spaced leaves (Bayley & Kellow 2006), it still meets the whipcord definition, so I treat it as a whipcord, as does Allan (1961).

Nearly all whipcord species of *Hebe* and *Leonohebe* occur in alpine areas and extend downslope into the subalpine zone (Table 1). Only *Leonohebe cupressoides* extends even further down into lowland areas, on 'alluvial terraces or colluvial slumps' (Widyatmoko & Norton 1997).

The six whipcord species of *Helichrysum* occur on cliffs and rock outcrops (Wardle 1991). Four have a montane to alpine range (Table 1), while *Helichrysum dimorphum* occurs in scrub on the walls of lowland river gorges (Wardle 1991); *Helichrysum intermedium* has a form on coastal cliffs (Wardle 1991).

South-eastern Australia

The whipcord species from this area are all shrubs in the tribe Gnaphalieae of the Asteraceae and comprise six species of *Ozothamnus* and one of *Leucophyta* (Table 2 and Figs. 1, 2, 3 and 4). Of the *Ozothamnus* species, two are from subalpine to alpine habitats, while the others are from lowland areas with significant summer water deficits (Table 2). *Leucophyta brownii* is a cushion plant from foredunes and cliffs on exposed coasts (Table 2). A number of other small-leaved species of both *Ozothamnus* (e.g. *Ozothamnus lycopodioides*) and *Olearia* (e.g. *Olearia teretifolia*) resemble whipcord species but fall outside the definition by having leaves which diverge somewhat from the stem.

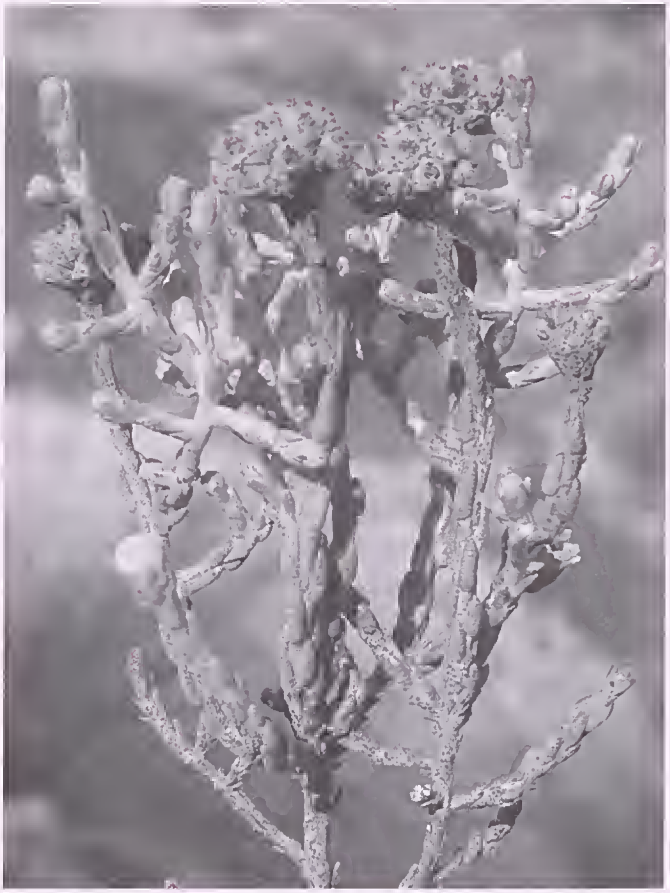


Fig. 3. Whipcord plant of *Leucophyta brownii*, Scamander, east coast Tasmania. Photo by David Tng.

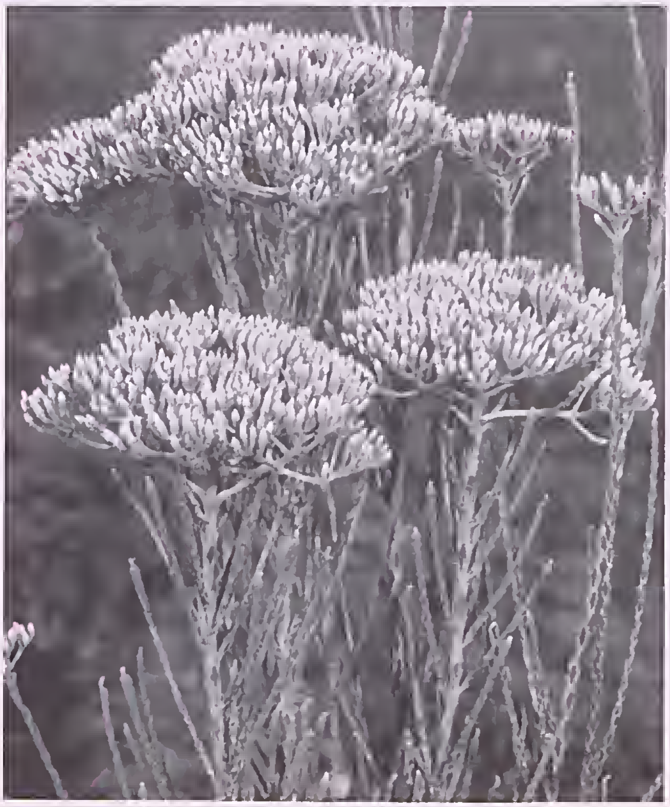


Fig. 4. Whipcord plant of *Ozothamnus pholidotus*, Glenisla Flats near the Grampians Ranges, Victoria. Photo by Bruce Fuhrer.

Discussion

Although use of the term 'whipcord' for some angiosperms has so far been virtually confined to New Zealand plants, it is not surprising to find that there are plants of identical life form in related lineages and habitats in Australia (Table 2) and elsewhere (see below). The most striking feature of the whipcord life form is small leaf size, which is clearly related to high levels of environmental stress (Wardle 1991). Four of the five whipcord genera dealt with here have some alpine to subalpine species where the main stresses will be a complex mixture of low temperature and low water supply effects (Korner 2003). However, both *Helichrysum* and especially *Ozothamnus* have some lowland species from habitats where the major stress will be periodic water deficit, well-known as one of the selective forces for small leaf size (Wardle 1991). In all cases, the whipcord life form may be regarded as a late stage in the evolutionary transition from large leaves to leaflessness as stress increases (see also Wardle 1991). In addition, the fact that the leaves of whipcord species are closely appressed to the stem will reduce their transpiration rate and, in the case of *Leucophyta brownii* and some populations of *Helichrysum intermedium*, the area exposed to salt spray.

Regarding the degree of phylogenetic relationship between the New Zealand *Helichrysum* whipcords and the Australian *Ozothamnus* ones, both genera are in the Tribe Gnaphalieae (Ward & Breitwieser 1998). All the whipcord species of *Helichrysum* will be relocated to other genera, but those genera do not include *Ozothamnus* (Ward & Breitwieser 1998, Breitwieser & Ward 2003).

It would be amazing if the whipcord habit was confined to Australasia and in fact, of the eight species of the Northern Hemisphere arctic-alpine evergreen shrub genus *Cassiope* (Ericaceae) described fully by Huxley (1999), six fall clearly within the whipcord definition and are actually referred to as 'whipcord-like' (Huxley 1999). Also, from the descriptions and illustrations, it is clear that the following South African Ericas are whipcords: *Erica alfredii* Guthrie & Bolus, *Erica corifolia* L., *Erica lutea* Berg., *Erica melanacme* Guthrie & Bolus, *Erica rhopalantha* Dulfer and *Erica scytophylla* Guthrie & Bolus (Baker & Oliver 1967), as are *Erica dominans* Killick (Killick 1997), *Erica juniperina* E.G.H. Oliv. (Oliver & Oliver 1995) and *Erica lachneaefolia* Salisb. (E.G.H. Oliver pers.comm.).

In the Cape region of South Africa, the shrub genus *Stoebe (Asteraceae)* includes three species, *Stoebe microphylla* DC, *Stoebe rugulosa* Harv. and *Stoebe schultzii* Levyns, which fall within the whipcord definition (Goldblatt & Manning 2000, Koekemoer 2002). Also, the bizarre South African shrub *Phaenocoma prolifera* (L.)D.Don (Asteraceae), where the tiny leaves 0.7mm long are carried on short side shoots up to 4mm long, also meets the whipcord definition (Hind 1996). All of the Asteraceous whipcord genera mentioned above are in the tribe Gnaphalieae. Within that tribe, enough phylogenetic data are available to show that the whipcord habit has arisen independently in a number of separate lineages (Bayer *et al.* 2000, 2002).

A final possible African connection comes from the name *Helichrysum selago*, previously used for the New Zealand whipcord *Helichrysum intermedium*. The specific epithet is explained as 'resembling *Selago*, an African genus'(Mark & Adams 1986), *Selago* being a genus in the Scrophulariaceae (previously including *Hebe*).

The only other whipcord species known to me is the north African-Eurasian tree *Tamarix aphylla*, which has tolerance to both drought and salinity (Parsons & Cuthbertson 2001). Detailed work may reveal further whipcords amongst scale-leaved members of the family Tamaricaceae.

Acknowledgements

I thank Dr. Trevor Edwards, Dr. Alison Kellow and Dr. Ted Oliver for advice and Bruce Fuhrer, Reg Morrison and David Tng for advice and for providing images.

References

Allan, H.H. (1961) *Flora of New Zealand.* Vol 1. Government Printer: Wellington.

Baker, H.A. & Oliver, E.G.H. (1967) *Ericas in Southern Africa.* Purnell: Cape Town.

Bayer, R.J., Greber, D.G. & Bagnall, N.H. (2002) Phylogeny of Australian Gnaphalieae (Asteraceae) based on chloroplast and nuclear sequences, the *trnL* intron, *trnL/trnF* intergenic spacer, *matK*, and ETS. *Systematic Botany* 27: 801–814.

Bayer, R.J., Puttock, C.F. & Kelchner, S.A. (2000) Phylogeny of South African Gnaphalieae (Asteraceae) based on two noncoding chloroplast sequences. *American Journal of Botany* 87: 259–272.

Bayley, M. & Kellow, A. (2006) *An Illustrated Guide to New Zealand Hebes.* TePapa Press: Wellington.

Breitwieser, I. & Ward, J.M. (2003) Phylogenetic relationships and character evolution in New Zealand and selected Australian Gnaphalieae (Compositae) inferred from morphological and anatomical data. *Botanical Journal of the Linnean Society* 141: 183–203.

Buchanan, A.M. (2009) *A Census of the Vascular Plants of Tasmania.* Tasmanian Herbarium: Hobart (www.tmag.tas.gov.au/Herbarium).

Cockayne, L. (1928) *The Vegetation of New Zealand.* Engelmann: Leipzig.

Curtis, W.M. (1963) *The Student's Flora of Tasmania.* Part 2. Government Printer: Hobart.

de Lange, P.J. & Norton, D.A. (2009) Threatened and uncommon plants of New Zealand (2008 revision). *New Zealand Journal of Botany* 47: 61–96.

Eagle, A.L. (2006) *Eagle's Complete Trees and Shrubs of New Zealand*. TePapa Press: Wellington.

Goldblatt, P. & Manning, J. (2000) *Cape Plants*. National Botanical Institute of South Africa: Pretoria.

Harden, G.J. (1992) *Flora of New South Wales*. Vol. 3. New South Wales University Press: Sydney.

Hind, N. (1996) 289: *Phaenocoma prolifera*. Compositae. *Curtis's Botanical Magazine* 13: 56–62.

Huxley, A. (1999) *The New Royal Horticultural Society Dictionary of Gardening*. Macmillan: London.

Killick, D.J.B. (1997) Alpine Tundra of Southern Africa. *In*: Wielgolaski, F.E. & Goodall, D.W. (Eds.) *Ecosystems of the World.3.Polar and Alpine Tundra*, pp. 199–209. Elsevier: Amsterdam.

Koekemoer, M. (2002) Systematics of the Metalasia group in the Relhaniinae (Asteraceae-Gnaphalieae). Ph.D. thesis, University of Cape Town.

Korner, C. (2003) *Alpine Plant Life*. Second ed. Springer: Berlin.

Mabberley, D.J. (2008) *Mabberley's Plant Book*. Third ed. Cambridge University Press: Cambridge.

Mark, A.F. & Adams, N.M. (1986) *New Zealand Alpine Plants*. Second ed. Reed Methuen: Auckland.

Oliver, E.G.H. & Oliver, I.M. (1995) Studies in the Ericaceae (Ericoideae) XVIII. Two new species of *Erica* from the southern part of South Africa. *Feddes Repertorium* 106:347–352.

Parsons, W.T. & Cuthbertson, E.G. (2001) *Noxious Weeds of Australia*. Second ed. CSIRO:Melbourne.

Puttock, C.F. (1999) *Ozothamnus*. *In* Walsh, N.G. & Entwisle, T.J. (Eds.) *Flora of Victoria* Vol. 4. Inkata Press: Melbourne.

Ward, J.M & Breitwieser, I. (1998) Systematics of New Zealand Inuleae (Compositae) – 4. A taxonomic review. *New Zealand Journal of Botany* 36: 165–171.

Wardle, P. (1991) *Vegetation of New Zealand*. Cambridge University Press: Cambridge.

Widyatmoko, D. & Norton, D.A. (1997) Conservation of the threatened shrub *Hebe cupressoides* (Scrophulariaceae), eastern South Island, New Zealand. *Biological Conservation* 82: 193–201.

Manuscript accepted 16 February 2010

Recent ecological observations on growth rates and seed production in *Isopogon prostratus* (Proteaceae), a little-known prostrate shrub from south-eastern NSW and Victoria

Doug Benson[1] and Lotte von Richter[2]

Botanic Gardens Trust, [1]Royal Botanic Gardens, Mrs Macquaries Rd, Sydney 2000 AUSTRALIA.
[2] Mount Annan Botanic Garden, Mount Annan, 2567, AUSTRALIA

Abstract: Observations on the longevity and ecology of *Isopogon prostratus* McGill. (Proteaceae) based on 1985 and 2009 field measures on Newnes Plateau, near Lithgow, and a seed germination trial are provided. Its survival strategy appears to be that of a stress-tolerator with long-term persistence at (relatively few) suitable sites, and it remains a relatively rare plant. It is conjectured that it is likely to have been a species of greater abundance in the drier, colder and generally treeless conditions of the Newnes Plateau 15–20 000 years ago, but, as conditions became warmer and wetter it has become reduced to isolated populations as taller shrubs outcompeted it for light.

***Cunninghamia* (2010) 11(3): 283–286**

Introduction and Methods

Isopogon prostratus McGill.(Proteaceae) is a little-known prostrate shrub with natural sporadic, disjunct occurrences from Newnes Plateau near Lithgow at 1100 m elevation in the north, along the southern ranges and onto the coast at Eden and the Gippsland Plain in Victoria (Figure 1, 2). It is generally localised to small populations with little apparent reason for presence or absence except that occurrences are generally in heath on plateaus and ridges (Benson & McDougall 2000). The species is listed as endangered in Victoria (Department of Sustainability and Environment 2005).

The population at Newnes Plateau came to our attention in the 1978 during environmental surveys of the area. A localised population in Newnes State Forest near Bungleboori Picnic area (33° 24" S; 150° 12" E, elevation 1100 m) was found in an area partly cleared in preparation for pine planting (it was previously relatively undisturbed native woodland), and fenced off from the adjacent pine plantation.

In 1985, 58 plants (all that could be found) in the fenced area of about a hectare were tagged, and the maximum canopy spread of all individuals was measured. This measure included the distance to the end of the longest branch. Branches spread radially and plants show no sign of vegetative spread such as layering or rooting along stems. In 2009 the site was revisited and individual plants relocated and their canopy spreads remeasured.

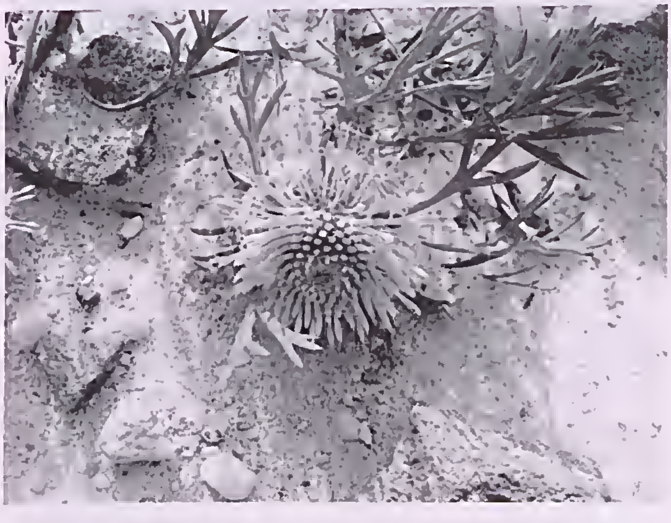


Fig 1. Inflorescence of *Isopogon prostratus* showing growing position at ground surface.

© 2010 Botanic Gardens Trust

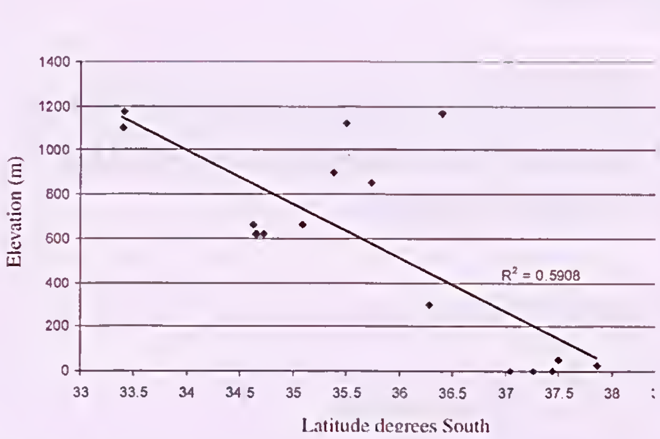


Fig 2. Relationship between elevation and latitude for populations of *Isopogon prostratus*, based on herbarium collections.

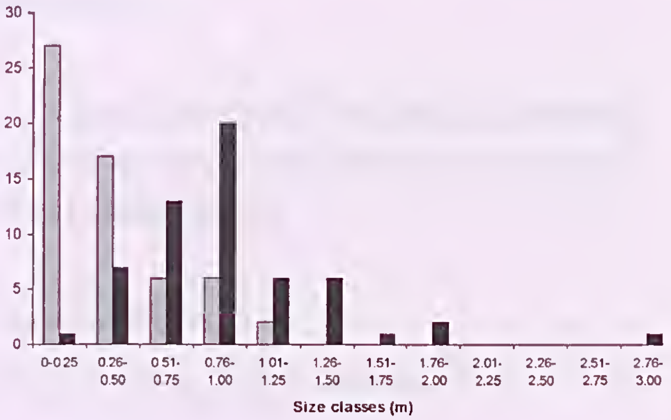


Fig 3. *Isopogon prostratus* size classes in 1985 and 2009 for 58 plants in Newnes State Forest.

In *Isopogon* the seeds are small one-seeded nuts held between persistent bracts that are tightly clustered in globular heads or cones. After fire the bracts open up releasing the nuts (Myerscough et al 2000). In 2009 cones were collected to test for seed viability. Cones along an individual branch from 10 plants were collected and dried to release the seeds. The maximum number of cones on any individual plant branch was 5. A total of 30 cones were collected and measured. Cones from 10 plants of *Isopogon anemonifolius* which commonly grows near *Isopogon prostratus*, were collected for comparison. Seed germination was carried out in a controlled environment cabinet set at 20° C with 12 hours light/dark.

Results

Since 1985 few additional individuals or populations of *Isopogon prostratus* have been recorded, either on Newnes Plateau, or over the species' general range.

In March 1985 the 58 marked and tagged individuals of the Newnes Plateau fenced population had canopy branch spreads ranging from 0.05–1.2 m (mean spread = 0.37 m se ± 0.04). In January 2009 spreads ranging from 0.2–3 m (mean= 0.94 m se ± 0.06).

It should be noted that during the January 2009 survey, only 3 of the original 58 metal tags attached to plants in 1985, were recovered. Remains of yellow plastic tape used in 1978 to mark plants were also found. Therefore, it is uncertain that the 58 plants inspected during the two survey periods (1985 and 2009) represent the same individuals, but it is likely that most of them are the same as all the observed plants had a substantial woody base or lignotuber, indicating longevity.

Based on canopy spread, the population size classes show a majority of small individuals (<0.25 m) in 1985, but by 2009 the majority fall within a larger class (0.76–1.0 m), with one individual up to 3 m across (Figure 3).

In 1978 the site had been roughly cleared and windrowed in preparation for pine planting, and existing plants may have been broken by scraping resulting in reduced canopy spreads. Small size does not necessarily indicate younger age. The site was described in 1978 as *the top end of sandy swamp in regenerating pine plantation with Eucalyptus dives and Eucalyptus radiata.* Since that time the fenced area has remained undisturbed except for the growth of the surrounding pine plantation, now 15 m in height, and the growth of native shrubs and grasses to 1 m high with a cover of 90% (mostly *Grevillea laurifolia, Phyllota squarrosa, Pteridium esculentum, Leptospermum polygalifolium*). Scattered trees of *Eucalyptus sieberi* and *Eucalyptus dives* to 10 m high are also present (Figure 4). There has been no fire or other disturbance over the 24 years since 1985 and probably over the 30 years since 1978.

Growth of *Isopogon* individuals takes place at the tips (10–20 cm) of long trailing branches (from 2–6 branches per plant) with flowering and fruiting cones produced periodically. In 2009 the majority of branches were buried in leaf litter and undergrowth. The tips however were found to have actively growing green leaves with some individuals flowering and fruiting this season despite relatively dry weather conditions. Individuals in full sun had more, but shorter branches, spreading radially whereas those under litter had fewer but much longer branches (generally only 1–2) as if spreading to reach more light.

The fruiting cones of *Isopogon prostratus* occur terminally on the current season's growth. The next vegetative growth flush occurs from just beneath the cone and forms an angular 'step' giving an indication of the number of growth seasons along a branch. The maximum number of these growth flushes observed was 12 so they do not necessarily represent annual growth. Older cones buried further back under the leaf litter had decomposed. The seeds are not released from the cone while still attached to the plant, but once cut from the plant, the cone opens readily and the hairy seeds fall out. They are likely to be released after fire as in *Isopogon*

Fig 4. *Isopogon prostratus* population site in Newnes State Forest in 2009.

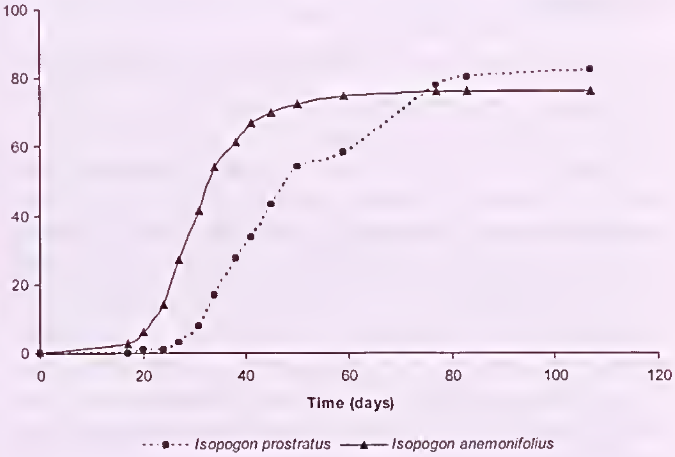


Fig 5. Seed germination of *Isopogon prostratus* and *Isopogon anemonifolius* over time in a controlled environment cabinet set at 20°C with 12 hours light/dark.

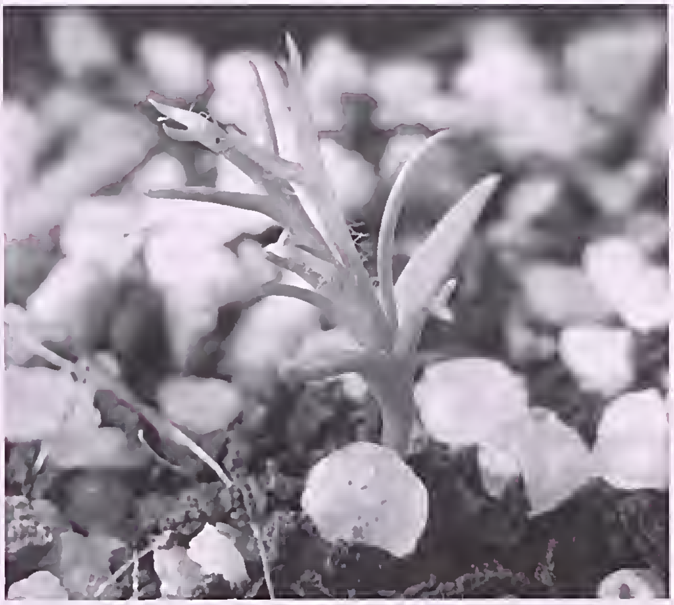


Fig 6. Seedling of *Isopogon prostratus* grown in glasshouse.

anemonifolius (Bradstock & Myerscough, 1988). There is no obvious dispersal mechanism for the seed as it is located at ground level.

No evidence of juveniles or seedling recruitment of *Isopogon prostratus* was observed in the field. Bradstock (1991) found significant predation of seedlings of *Isopogon anemonifolius* in unburnt areas by unidentified animals, but this was not possible to determine at the Newnes site.

Comparison with Isopogon anemonifolius

Cones of *Isopogon prostratus* and the similar but erect shrub *Isopogon anemonifolius* were of similar size but *Isopogon prostratus* had nearly twice as many seeds per cone (41 ± 7) (Table 1).

Seed was produced from cones from a number of seasons/ growth flushes (up to 5) indicating pollination and seed set have been occurring, but seed release leading to germination has not been observed in the field. Under controlled conditions in the laboratory, seed germination for *Isopogon prostratus* began after 20 days and for *Isopogon anemonifolius*, after 17 days (Figures 5,6). Germination was quicker for *Isopogon anemonifolius* which finished by day 60, but *Isopogon prostratus* continued up to day 107. Both species achieved about 80% germination.

There was no difference in germination rates from different-aged cones collected from individual plants. Likewise there was no distinctive decline in seed viability for the different aged cones. In the field cones of *Isopogon prostratus* appear to decay more rapidly than those of *Isopogon anemonifolius*, as being on the soil surface, they are likely to be covered by litter and are more exposed to moisture and microbial activity.

Table 1: Comparison of cone size and seed number for *Isopogon prostratus* and *Isopogon anemonifolius*

		Isopogon prostratus	*Isopogon anemonifolius*
Cone diameter (mm)	Maximum	27.4	25.1
	Minimum	13	17.2
	Mean (± s.e.)	19.6 (± 0.6)	20.1 (± 0.3)
	n	30	42
Seed number/ cone	Maximum	153	60
	Minimum	0	6
	Mean (± s.e.)	41 (± 7)	26 (± 2)

Discussion

On the Newnes Plateau *Isopogon prostratus* is at its northern geographical limit and upper elevational limit. Individual plants are relatively long-lived with substantial lignotubers allowing them to survive an overstorey removal event (surface vegetation clearing) and to live at least 30 years under subsequent overstorey regrowth. The substantial lignotuber is likely to allow this regrowth to be repeated following disturbance e.g. in response to fire (though no burnt individuals have been observed) or other canopy destruction, giving a potential longevity of several to many times 30 years (perhaps 60–200 years). Mortality at this site is likely to occur as a result of physical disturbance of the lignotuber or disease.

The prostrate growth habit of *Isopogon prostratus* allows it to grow well in full sun or partial shade, while its long-lived lignotuber allows it to regenerate after physical disturbance (breaking, trampling) and fire. The germination trial indicates the Newnes population produces viable seed; therefore pollination and seed set are not limiting factors to its survival. Its poor dispersal ability presumably allows local occurrences to be maintained though no new individuals or evidence of seedling recruitment were evident in 2009, following several decades of general overstorey canopy growth, and absence of fire or disturbance. In terms of Grime's (2001) functional strategies the species is a Stress-tolerator. Its survival strategy is long term persistence at (relatively few) suitable sites, and as such, it remains a relatively rare plant.

Threatening processes for the long-term survival of *Isopogon prostratus* are direct destruction (through sand extraction, infrastructure and road construction) or physical damage of branches by trampling (through trailbikes, vehicles and vegetation clearing). Species of *Isopogon* in Western Australia and Victoria are susceptible to the root-rotting mould *Phytophthora cinnamomi*, and hence may be of concern for *Isopogon prostratus* if introduced to areas of known populations. Most of these threatening processes are likely to operate across its range.

Conjecture (for testing)

It is our conjecture that *Isopogon prostratus* is likely to have been a species of greater abundance in the drier, colder and generally treeless conditions of the Newnes Plateau at the time of the last glacial maximum 15–20 000 years ago (Hesse et al, 2003) (e.g. the hairy seed is more likely to have dispersed further by wind in drier open conditions), but has become reduced to isolated and disjunct populations as taller shrubs outcompeted it for light, as conditions became warmer and wetter. Its limited dispersal and current disjunct occurrences suggest it previously had a much more continuous distribution between Newnes Plateau and Victoria. To test this, research on the tolerance limits of the species (maximum and minimum temperatures for growth, flowering, seedset, germination etc, moisture and light requirements) and levels of genetic variation is needed. Such work is likely to throw light on the dynamics of the species during the climatic changes of the last 20 000 years, and provide a sounder base for modelling likely future changes in vegetation patterns impacted by climate change.

Acknowledgments

We acknowledge NSW Forests for fencing the *Isopogon* population in 1978 and subsequent maintenance, and forester Stephanie Hutcheson for encouraging us to revisit the site. Tracey Austin (nee Goodwin) helped record the plants in 1985 and Liz Norris provided helpful comments on the manuscript.

References

Benson, D. & McDougall, L. (2000) Ecology of Sydney Plant Species Part 7b: Dicotyledon families Proteaceae to Rubiaceae. *Cunninghamia* 6(4): 1017–1202.

Bradstock, R.A. (1991) The role of fire in establishment of seedlings of serotinous species from the Sydney region. *Australian Journal of Botany* 39: 347–356.

Bradstock, R.A. & Myerscough, P.J. (1988) The survival and population response to frequent fires of two woody resprouters *Banksia serrata* and *Isopogon anemonifolius*. *Australian Journal of Botany* 36: 415–431.

Department of Sustainability and Environment (2005) *Advisory List of Rare or Threatened Plants in Victoria–2005.* (Victorian Department of Sustainability and Environment: East Melbourne, Victoria).

Grime, J.P. (2001) *Plant strategies, vegetation processes, and ecosystem properties* (John Wiley & Sons: Chichester)

Hesse, P.P., Humphreys, G.S., Selkirk, P.M., Adamson, D.A., Gore, D.B., Nobes, D.C., Price, D.M., Schwenninger J.-L., Smith, B., Tulau, M. & Hemmings, F. (2003) Late Quaternary aeolian dunes on the presently humid Blue Mountains, Eastern Australia. *Quaternary International* 108: 13–32.

Myerscough, P.J., Whelan, R.J. & Bradstock, R..A. (2000) Ecology of Proteaceae with special reference to the Sydney region. *Cunninghamia* 6(4): 951–1015.

Manuscript accepted 16 February 2010

Waratah theft in Brisbane Water National Park – an analysis of the blue paint poaching reduction program

Doug Beckers[1] *and Catherine A. Offord*[2]

[1] Parks and Wildlife Division, Department of Environment, Climate Change and Water PO Box 1477 Gosford NSW 2250 AUSTRALIA;
Email: *doug.beckers@environment.nsw.gov.au*
[2] Botanic Gardens Trust, Mount Annan Botanic Gardens, Mount Annan Drive, Mount Annan, NSW 2567 AUSTRALIA.

Abstract: The flowers of Waratahs, *Telopea speciosissima* (family Proteaceae) are regularly harvested illegally from natural bushland, particularly close to urban areas such as the New South Wales Central Coast. The removal of Waratah blooms from the wild may have implications for the long-term survival of local populations because of the interaction between wildfire events, subsequent flowering and limited seedling recruitment opportunities.

To reduce the incidence of theft, blue acrylic paint was applied to blooms to reduce their commercial value. The painting of blooms in 2004 did not significantly reduce the incidence of wildflower theft when compared to unpainted blooms, but overall losses were lower (27%) than in 2003 (33%). However, painting of blooms had a deleterious affect on fruit production on plants with multiple heads with painted blooms having significantly redueed fruit set compared to unpainted blooms. Painting of blooms had no significant effeet on seed quality (seed production per fruit, seed germination or seedling vigour) when compared to unpainted blooms.

The painting of Waratah blooms to reduce theft was relatively ineffective and decreased fruit production. Alternative strategies should be considered to reduce wildflower theft in the area.

Key words: Waratah, *Telopea speciosissima*, bush-harvesting, seed production seed germination, flower theft, fire management, adaptive management

Cunninghamia **(2010) 11(3): 287–293**

This paper is dedicated to the memory of George Robertson who tragically passed away before the completion of this study.

Introduction

The theft of plants and plant parts from the wild has been reported as an issue of concern in many countries. Timber theft is common in many countries; see Blundell and Mascia (2005) and Rodriguez (2000). Carnivorous plants (Robbins 1998), moss (Muir et al. 2006) and orchids (Sharma et al. 2003) are the targets of poachers in the United States. In Mexico, the theft of cacti (Godinez-Alvarez et al. 2003) and in Belize the theft of palm fronds for floriculture is common (Bridgewater et al. 2006). Callister and Williams (2000) discuss orchid, palm, fern and cycad theft in Australia and indicate that information on the extent and impact of illegal plant collection is not readily available.

The Waratah, *Telopea speciosissima* (Smith) R.Br.), a spectacular wildflower in the Proteaceae family and the floral emblem of the state of New South Wales (NSW) is restricted to localized pockets in the Sydney region and Blue Mountains, from the Watagan Mountains south to Ulladulla (Harden 2002). The flowering head, collectively known as a bloom, is a colleetion of about 80–250 flowers per conflorescence (Pyke 1981) and is a highly desirable cut-flower commodity. Waratahs are proteeted in NSW as a species of high conservation value (NSW National Parks & Wildlife 2002) and because there is a sustainable cut-flower industry based on plantation-grown Waratahs of commercially developed cultivars (Offord 1996), no pickers or wild-harvest licences are issued.

Waratahs bloom between August and November. Poaching of flowers in wild stands has been reported throughout the natural range of oecurrence, but is particularly prevalent close to urban areas. On the Central Coast of NSW, local residents of Patonga near Gosford approached the National Parks and Wildlife Service (NP&WS) with concerns that

© 2010 Botanic Gardens Trust

Waratah blooms were being deliberately picked from the wild from the 'Waratah Patch' in Brisbane Water National Park. The residents were concerned that the picking would reduce Waratah flowers available for seasonal wildflower viewing by park visitors. While investigating Waratah demography at the same site in 1987, Bradstock (1995) noted 'flower picking in some sites adjacent to roads'. During Waratah flowering season, visitors travel considerable distances to view these wildflowers and the local NPWS officers wanted to maximize the wildflower experience for visitors by reducing wildflower theft.

Waratah flowering is linked to wildfire events (Pyke 1981) and in the 1970s and early 1980s, sections of the 'Waratah Patch' were deliberately burnt every 6 years to encourage the Waratah flowering (Ian Webb pers. comm. 2006). Waratahs are one of a few species of Proteaceae that do not form persistent seed banks, but release non-dormant seeds following post-fire resprouting and flowering (non-bradysporous resprouters with non-dormant seed) (Myerscough et al. 2000, Denham & Auld 2002). Waratahs that survive summer wildfires resprout from vegetative tissue stored below the ground; the subsequent growth produces flowers the second spring after fire, with peak flowering occurring August – early September (Bradstock 1995, Denham & Auld 2002). The number of blooms produced decreases with time since fire, with flowering almost ceasing 5 years post-fire (Pyke 1983); seed production is generally restricted to the first 3 post-fire flowering years (Denham & Auld 2002). Because of this natural reduction in flowering and the reduction in fruit and seed production plus the fact that the seeds are non-dormant, the opportunity for seedling recruitment is restricted to the few years post-wildfire.

The removal of Waratah blooms may also be affecting the fecundity of the remaining unpicked Waratahs. In the closely-related Western Australian species *Banksia hookeriana* the reduction of flower numbers through commercial picking resulted in reduced seed production and storage in the remaining unpicked flowers (Witkowski et al. 1994).

The theft of Waratah flowers has been a conservation issue for reserves of the Central Coast Hunter Range, Sydney North and Sydney South NP&WS Regions. Rangers have attempted to reduce the amount of Waratah theft by spraying blooms with blue paint to make the flowers less attractive to plant thieves and to reduce their commercial value (Neil Martin and Teagan Burton pers. comm., Beale 1997). However, the degree of Waratah theft has not been quantified, nor whether the painting of the blooms reduces wildflower theft. The effect of the painting on the ecology of the Waratahs has not been investigated. This study investigated the degree of Waratah theft in the 'Waratah Patch', whether media coverage, signage, educational walks and the painting of Waratah blooms would reduce Waratah flower theft, and the influence that painting of blooms had on fruit and seed production, seed germination, seedling germination rate and seedling vigour.

Methods

Study Area

The 'Waratah Patch' in Brisbane Water National Park is between Pearl Beach and Patonga about 80 km north of Sydney (lat: 33° 32' S; long: 151 ° 17' E). The Waratahs are restricted to an isolated occurrence of deep sandy lateritic loam of very low soil fertility and low relief, mapped as Somersby soil landscape unit in a matrix of contrasting sandstone-derived shallow soils of the Lambert and Hawkesbury soil landscape units (Chapman & Murphy

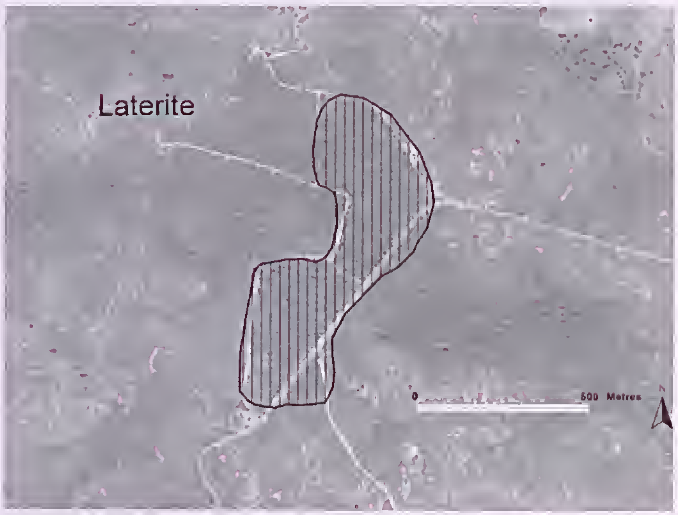


Fig. 1. The fire trail network surrounding the lateritic 'Waratah Patch' was constructed to facilitate the frequent burning to encourage Waratah flowering, a practice which ceased around the early 1980s.

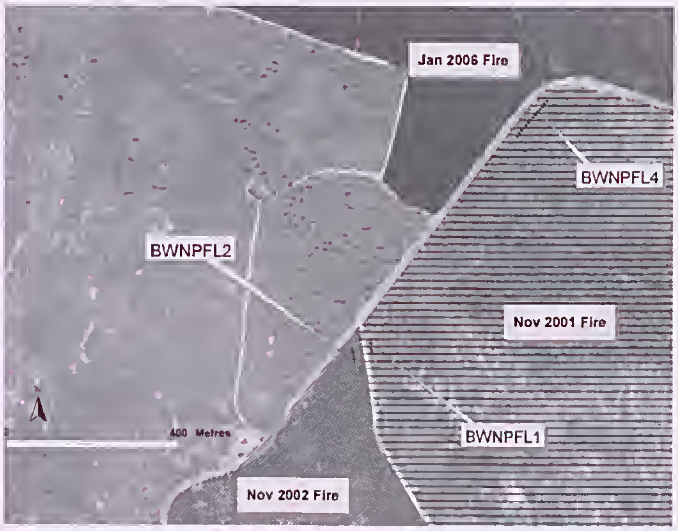


Fig. 2. The recent fire history of the site initiated the mass flowering of Waratahs. The entire area was burnt by wildfire in 1990 and sections of the 'Waratah patch' were burnt again in November 2001, November 2002 and January 2005. Transect locations indicated

1989). The fire trail network was constructed to facilitate the frequent burning of the 'Waratah Patch' to encourage Waratah flowering, a practice that ceased in the early 1980s (Fig. 1). The vegetation of the site is low open forest, mapped as Community 4P, Open Forest to Low Open Forest (Benson & Fallding 1981). Local dominants in the tree layer include *Eucalyptus haemastoma, Eucalyptus oblonga* and *Corymbia gummifera.* Shrubs include *Phyllota phylicoides, Boronia ledifolia, Pimelea linifolia, Platylobium formosum, Acacia myrtifolia, Acacia ulicifolia* and a high diversity of plants from the Proteaceae family including *Lambertia formosa, Persoonia levis, Banksia serrata, Banksia spinulosa, Banksia ericifolia, Conospermum longifolium, Grevillea buxifolia, Grevillea sericea, Hakea dactyloides, Isopogon anemonifolius, Petrophile pulchella* and *Xylomelum pyriforme.*

The entire area was burnt by wildfire in 1990 and sections of the 'Waratah patch' were burnt again in November 2001, November 2002 and January 2005 (Fig. 2) initiating a mass Waratah flowering.

Effects of painting on theft reduction

To determine the degree of wildflower theft, 3 transects were set up, two within the 2001 burn area (BWNPFL1 29.8 m long and BWNPFL4 83.5 m long) and the third (BWNPFL2 28.6 m long) within the 2002 burn area (Fig. 2). Each transect was marked with a single permanently placed stake at each end, so that repeated measurements could be taken. On 1st September 2003 a measuring tape was laid along the length of each transect, and the location of every flowering stem recorded as the distance from one end of the transect, plus the perpendicular distance from the tape, up to a distance of 10 m from the tape (i.e. an effective 20 m wide transect was sampled). The numbers of stems clean cut or snapped were recorded. Transects were resampled on the 22nd October 2003 to record the number of blooms removed and method of removal.

To determine whether the painting of blooms blue reduced the rate of bloom theft, 300 plants were chosen, with 100 painted (treatment) and 200 unpainted (control) blooms. Every Waratah plant with a bloom was sampled within the 2001 burn area (135 plants) and 165 plants, which were approximately 75% of all blooms at the site, were sampled in the 2002 burn area. Plants varied from having a single stem with a single bloom, to multiple stems each stem with a single bloom, or single stems with multiple blooms. Every third flowering Waratah plant was chosen for painting, and the intervening two plants used as controls. The blooms were only painted if the floral bracts were fully coloured (red) and expanded and the flowers were close to or beginning to open (Offord 2004). The painted plants had a patch of blue acrylic paint ('Burton Blues', low sheen acrylic, Berger Paints) hand-applied with a paintbrush to the three uppermost leaves closest to the bloom, a single patch of paint applied at the base of the bloom on the flower stalk and a small amount of paint, approximately 15 mm square, applied to each of three floral bracts (Fig. 3). When a plant to be painted had multiple blooms on the one stem, every bloom on the plant was painted. The height from the ground to the top of every bloom was measured using a surveyor's staff, the number of blooms on each stem recorded, and every plant tagged with a numbered aluminum tag and location recorded using a Garmin 76 GPS unit (between 3–6th September 2004) (Fig. 4).

The plants were assessed on 22nd December 2004 and the number of flowers removed recorded as either a clean cut or snapped. The number of fruits which developed on the remaining flowers was also recorded. For the analysis of the data, stems with multiple blooms were treated as a single unit.

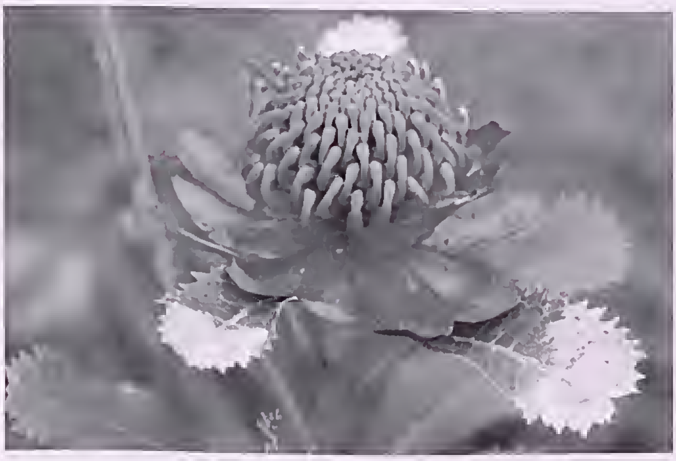


Fig. 3. The painted plants had a single patch of blue acrylic paint hand applied with a paintbrush to the three uppermost leaves closest to the flower head, a single patch of paint applied at the base of the flower on the flower stalk and a small amount of paint, approximately 15mm square, applied to each of three floral bracts.

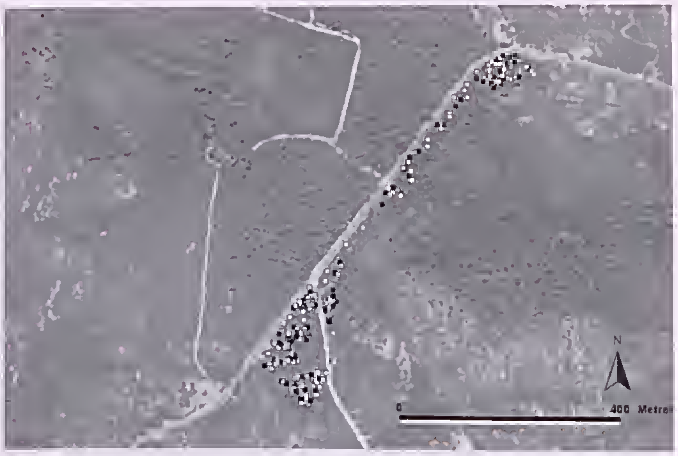


Fig. 4. The locations of tagged Waratah plants were recorded using a Garmin 76 GPS unit, painted plants are shown with a black square, unpainted plants shown with a white square.

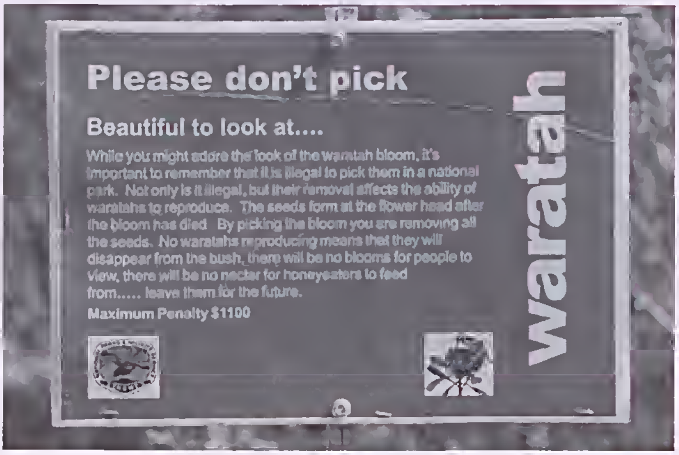
Effect of painting on fruit and seed production

During late March 2005, 20 each of both painted and unpainted blooms that developed fruits were randomly selected and a single fruit from each selected plant was removed and allowed to dry in a paper bag. Each fruit was labelled according to the plant and applied treatment (painted or unpainted). The fruits were air dried on the laboratory bench until they had split and reflexed sufficiently to expose the seeds. The seeds belonging to each fruit were then counted and kept in separately labelled packets. Once the fruits opened, the number of filled seeds (see Denham & Auld 2002) and empty seeds per fruit were recorded.

Effect of painting on seed germination and seedling vigour

A total of 180 fresh seeds each from painted and unpainted blooms were sown onto 7 g.L^{-1} agar in 40 mm diameter petri dishes (ten dishes for each treatment, each containing 18 seeds randomly assigned within the treatment dishes). Dishes were labelled such that the seed could be traced back to the original fruit/plant/treatment. The petri dishes were placed into a Thermoline incubator set at constant 20°C (±1), with 12 hours light in the diurnal period. Seeds were checked twice daily (7 am and 4 pm) for germination which was recorded when 2 mm of root was visible. Seedlings were then placed into potting mix in a 50 mm growing tube and grown in a glasshouse. Plant vigour was assessed by recording the survival, height and general appearance of the seedlings 30 and 90 days after germination.

The average cumulative seed germination for each replicate dish was calculated and plotted against the hours taken to germinate. Time to initial germination (T_i), time to 50% germination (T_{50}), time to maximum germination (T_{100}) and plant heights were compared for each treatment by a one-way ANOVA. The overall percentage of seeds germinated (G_{MAX}) was compared by one-way ANOVA, following Arcsin transformation of the data.



Please don't pick

Beautiful to look at....

While you might adore the look of the waratah bloom, it's important to remember that it is illegal to pick them in a national park. Not only is it illegal, but their removal affects the ability of waratahs to reproduce. The seeds form at the flower head after the bloom has died By picking the bloom you are removing all the seeds. No waratahs reproducing means that they will disappear from the bush, there will be no blooms for people to view, there will be no nectar for honeyeaters to feed from..... leave them for the future.

Maximum Penalty $1100

waratah

Fig. 5. Signs warning people not to pick the Waratah blooms were installed at several locations.

Media, signage and education walks.

A newspaper article highlighting the problem of Waratah theft accompanied with photographs, appeared in the local press during late September 2004 (Stubbs 2004). An interview at the site with ABC local radio was also aired on the Central Coast in September 2004. Signs warning people not to pick the Waratah blooms (Fig. 5) were installed at several locations. Guided education walks were conducted by NPWS staff at the site on 3rd September 2004, with over 25 people in attendance.

Results

Effects of painting on theft reduction

A significant rate of Waratah theft was recorded along the transects over the 52 day period in 2003 (Table 1) with overall losses of 32% and one transect losing 85 % of blooms. The majority of blooms were snapped with only a few removed with a clean cut.

In the spring of 2004 the overall theft rate of flowering stems was 27%, with 81% of these blooms being removed with a clean cut and the remainder being snapped. There was no significant difference between the rate of theft of painted stems compared to unpainted stems, although fewer painted stems were removed than unpainted stems (Table 2).

Effect of painting on fruit and seed production

Painting of blooms significantly suppressed fruit production when the stems had multiple blooms, but not when stems had single blooms (Table 3).

The blooms that did produce fruit showed no significant difference in the number seeds produced per fruit between

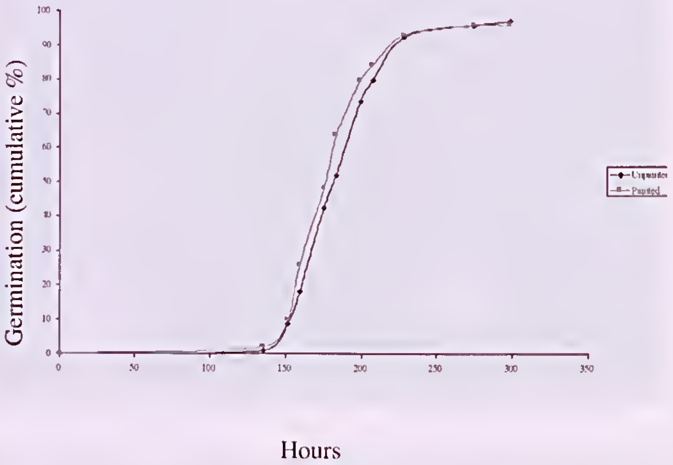


Fig. 6. Cumulative germination of fresh Waratah seeds from Brisbane Water NP at 20°C (12 hr light): comparison of seeds from untreated blooms and blue marker painted blooms.

Table 1. Waratah theft: the number of blooms observed, and subsequently removed along 3 transects in Brisbane Water National Park during a 52 day period in 2003.

Transect	Last burnt	Total no of blooms (1 Sept 2003)	No of blooms picked (1 Sept 2003)	No of blooms picked (22 Oct 2003)
BWNPFL4	Nov 2001	92	7	19
BWNPFL1	Nov 2001	19	1	17
BWNPFL2	Nov 2002	3	1	1

Table 2. Effects of painting on theft reduction: the proportion of blooms removed from painted and unpainted treatments.
(Statistical differences χ^2, NS1=non-significant, P=0.082; NS2=non-significant, P=0.599; NS3=non-significant, P=0.113).

	Single Blooms	Multiple Blooms	All stems
Unpainted Plants	29.9% NS1 (n=251)	18.8% NS2 (n=16)	29.1% NS3 (n=267)
Painted Plants	21.1% NS1 (n=114)	28.6% NS2 (n=7)	21.5% NS3 (n=121)

Table 3. Effect of painting on fruit and seed production: the proportion Waratah blooms that produced fruit according to the number of blooms produced per stem and whether the blooms were painted or unpainted.
(Statistical differences χ^2, NS1=non-significant, *P=0.0085).

	Single Blooms	Multiple Blooms
Unpainted Plants	40.7% NS1 (n=177)	62.9%* (n=13)
Painted Plants	32.2% NS1 (n=90)	0%* (n=5)

Table 4. Germination of fresh Waratah seeds from Brisbane Water National Park: comparison of seeds from untreated blooms and blue paint treated blooms.
T_I = average time to initial germination (hr), T_{50} = average time to 50% germination (hr), T_{100} = average time to 100 of germination (hr), G_{Max} = maximum germination (% $\pm$se). There was no significant difference between the treatments for any germination variable measured.

	Unpainted blooms	Painted blooms
T_I (hr)	151.8 ± 3.0	147.6 ± 2.9
T_{50} (hr)	187.0 ± 3.4	179.0 ± 2.5
T_{100} (hr)	265.0 ± 8.6	243.5 ± 8.8
G_{Max} (%)	97.2 ± 0.8	97.2 ± 0.9

Table 5. Seedling vigour of Waratahs from Brisbane Water National Park: comparison of height, number of leaves and survival of seedlings from untreated blooms and blue paint treated.
There were no significant differences between the treatments, except for height at 30 days (P=0.002).

	Unpainted blooms		Painted blooms	
	30 days	90 days	30 days	90 days
Height (mm)	34.65 ± 0.7	98.1 ± 2.4	37.3 ± 1.0	104.9 ± 2.0
Number of leaves	1.48 ± 0.05	9.28 ± 0.19	1.71 ± 0.09	9.20 ± 0.14
Survival (%)	93.1 ± 1.8	90.8 ± 2.3	96.6 ± 1.5	95.5 ± 2.0

unpainted plants (15.8 seeds/fruit) compared to fruits from painted plants (15.7 seeds/fruit). The number of filled seeds per fruit did not differ significantly between unpainted (12.1 seeds/fruit) and painted plants (11.5 seeds/fruit).

Effect of painting on seed germination and seedling vigour

No significant difference was detected between the treatments for seed germination or the seedling growth variables recorded, with the exception of the plant height at 30 days which was greater in the painted treatment (*P*=0.002). However, this difference was no longer significant at 90 days (Tables 4 and 5, Fig. 6).

Discussion

Despite signage, media coverage, educational walks and painting of about a third of all Waratah blooms, over 26% of blooms, were stolen from the study area during the large flowering event in 2004. Although this is a lower loss than for 2003 (32%), it represents a substantial reduction in reproductive material for the species. Indeed increasing the profile of the flowering event through media coverage may in fact have contributed to the rate of theft by raising public awareness of the timing of the flowering.

Because of the high degree of theft, there is the question of why are the blooms stolen? The 2004 census revealed the majority (81%) of flowers were deliberately cut. When the fruits were being collected in March 2005 for the germination study, a bunch of seven picked flowers with stems averaging 80 cm long, each with a clean cut at the base were found withered on the ground. These flowers could have been destined for the cut flower market, as blooms in local florists at the time were fetching up to $12 per bloom.

Painting of blooms

The painting of Waratah blooms did not greatly reduce the amount of Waratah theft at this time within Brisbane Water National Park. A theft reduction program using paint conducted at several locations across a number of seasons would provide valuable information as to the robustness of this management action. The lack of fruit developed on the multiple bloomed plants may be due to a toxic effect of the paint on the fruit, in which case the use of a different type of paint could be explored. However, it is more likely that blue paint may deter the major cross- pollination vectors, birds, thus resulting in lower fruit set as Waratahs are on obligate outcrossing species. (Whelan & Goldingay 1989, Offord 2004) The phytotoxicity of paint treatments appears to vary between species as studies on seed germination of different conifer species showed that one species (Western larch) was affected by a range of paint formulations while three other species were unaffected (Dumroese 2003). Regardless of the potential phytotoxicity of the paint, the fact that fruit production was reduced in multiple bloomed plants is a cause for concern, although in this study the sample number was very low. The results of this study indicate that the painting of waratah blooms had minimal affect on reducing flower theft, and it is recommended that painting of blooms be discontinued as a flower theft reduction strategy.

But why were painted Waratah blooms picked at all? The answer to this question may lie in the timing of picking events. It seems logical for theft to occur when the likelihood of detection is at its lowest, hence theft in darkness or low light conditions is a likely possibility and the blue colour of the paint may not be discernable during low light conditions. Perhaps surveillance during the early morning and evening and using an alternative paint colour may reduce the rate of theft.

Because fruit production and seedling recruitment of Waratahs is basically restricted to the first few years post-fire (Denham & Auld 2002), the removal of over a quarter of the flowering heads by theft, and the subsequent reduction in seed production, may be affecting the population dynamics at the site. Bradstock (1995) recognized that high intensity burning at too frequent intervals, coupled with flower picking, could result in the depletion of local populations of Waratahs. Fortunately, the high intensity frequent fires have been reduced, with over 41% of the 'Waratah patch' remaining unburnt since 1991. Heavy picking of plant parts early in this cycle may affect not only the seed production ability and hence seedling recruitment, but the ability of the plants to regenerate by post-fire sprouting. Loss of nutrients, particularly nitrogen, following bush picking has been reported in natural stands of *Banksia hookeriana* (Witkowski & Lamont 1994) though studies on South African Proteaceae suggest that up to 80% of blooms can be harvested in some species without significantly reducing population seed fecundity (Maze & Bond 1996). Given that the species and habitats in these studies are different, it would be useful to study sustainable harvest levels in Waratah populations to determine the upper limit for this species in a given situation. Regardless, in areas such as National Parks where Waratah flowering is an annual tourist attraction, any loss of flowers is detrimental to the population.

The flowering Waratahs in this study were all close to the main road or management tracks with no picked Waratahs occurring further than 65 m from an access track. It is possible that the likelihood of picking is reduced in other areas of the 'Waratah patch' where Waratah plants are growing further from access roads and tracks.

Waratahs are easy to propagate from fresh seed as the germination data indicates, yet there was no evidence of fruit poaching; of the 40 plants randomly selected for fruit collection, only one plant could not be located. Horticultural waratah selections are now widely available in plant nurseries; this may be benefiting wild population by reducing the demand for wild seed.

Other theft reduction strategies

Other strategies that could be employed to reduce the amount of bloom theft, include increased surveillance. This need not be ongoing, as flowering is restricted to a 6–8 week period and in terms of seedling recruitment potential, only lasts for about 4 seasons after the initial post-fire flowering. Another strategy could be the establishment of a 'Waratah Watch' program, as there is considerable local interest in reducing the theft of the flowers.

In summary, the painting of blooms to reduce Waratah flower theft was found to be relatively ineffective, and led to reduced seed production in stems with multiple blooms. The painting of blooms is therefore not recommended. However the study is a good example of how research can be of benefit to adaptive management in the Park. The study resulted in the re-evaluation of current Waratah theft reduction strategies. Because of the deleterious affect to wildflower displays and visitor enjoyment, and the potential long term affect on the Waratah population, strategies to reduce Waratah theft should continue to be employed, particularly in the first few years after fire when the plants are fruiting.

Acknowledgements

Rob Suesse, Di Hattersley, Vicki Elliott, Mary Ghosn, Deb Holloman, Amelia Martin, George Robertson, Neil Martin, Dave Kelly, Kim West and Barbara Jackson and John Adams (Patonga Landcare) all helped with field work, and thanks to Andrew Denham for useful comments on the manuscript.

References

Beale, B. (1997) Waratah poachers foiled by a spray of colour. *Sydney Morning Herald*, October 13.

Benson, J.S. & Fallding, H. (1991) Vegetation Survey of Brisbane Water National Park and Environs *Cunninghamia* 1 (1) 79–113

Blundell, A.G; Mascia, M. B 2005 Discrepancies in Reported Levels of International Wildlife Trade *Conservation Biology*. 19 2020–2025.

Bradstock R.A. (1995) Demography of woody plants in relation to fire: *Telopea speciosissima*. *Proceedings of the Linnean Society of New South Wales* 115, 25–33.

Bridgewater, S.G.M., Pickles, P., Garwood, N.C., Penn, M., Bateman, R.M., Morgan, H.P., Wicks, N., & Bol, N. (2006). *Chamaedorea* (Xaté) in the Greater Maya Mountains and the Chiquibul Forest Reserve, Belize: An Economic Assessment of a Non-Timber Forest Product. *Economic Botany* 60, 265.

Callister D.J. & Williams, L.M. (1995) *Australia's native wildlife trade: scale, trends and impacts*. In *Conserving Biodiversity: Threats and Solutions*, ed by R. A. Bradstock, T. D. Auld, D. A. Keith, R. T. Kingsford, D. Lunney & D. P. Sivertsen. Surrey Beattie & Sons.

Chapman G.A. & Murphy, C.L. (1989) *Soil Landscapes of the Sydney 1:100,000 Sheet* Soil Conservation Service of NSW, Sydney.

Denham, A.J & Auld, T.D. (2002) Flowering, seed dispersal, seed predation and seedling recruitment in two pyrogenic flowering resprouters. *Australian Journal of Botany* 50, 545–557.

Dumroese, R.K. (2003) Technical note – Marking tree seeds with spray paint for germination studies. *Western Journal of Applied Forestry* 18, 175–178.

Godinez-Alvarez, H., Valverde, T., & Ortega-Baes, P. (2003) Demographic trends in the Cactaceae. *Botanical Review* 69, 173–203.

Harden, G.J. (2002) *Flora of New South Wales* (2nd Edition). University of New South Wales Press, Sydney.

Maze, K.E. & Bond, W.J. (1996) Are Protea populations seed limited? Implications for wildflower harvesting in Cape fynbos. *Australian Journal of Ecology* 21, 96–105.

Muir, P. S.; Norman, K. N.; Sikes, K. G. (2006) Quantity and value of commercial moss harvest from forests of the Pacific Northwest and Appalachian regions of the U.S. *The Bryologist* 109, 197–214

Myerscough P. J., Whelan, R. J. & Bradstock, R. A. (2000) Ecology of Proteaceae with special reference to the Sydney region. *Cunninghamia* 6 (4), 951–1015.

NSW National Parks & Wildlife Service (2002) *Protected and threatened plants in the cut-flower industry: Management Plan 2002–2010*. Accessed 25th July 2006 @ http://www.environment.gov.au/biodiversity/trade-use/sources/management-plans/flora-nsw/pubs/cut-flower.pdf

Offord, C.A. (1996). Waratahs. In *Horticulture of Australian Plants*. (Eds M. Burchett & K. Johnston). pp. 67–81. (UNSW Press: Sydney).

Offord, C.A. (2004). An examination of the reproductive biology of *Telopea speciosissima* (Proteaceae) with emphasis on the role of protandry and self-pollination in fruit set. *International Journal of Plant Sciences* 165: 73–83.

Pyke G. H. (1981) Effects of inflorescence height and number of flowers per inflorescence on fruit set in Waratahs (*Telopea speciosissima*). *Australian Journal of Botany* 29, 419–424.

Robbins, C. S. (1998) Examination of the US Pitcher-plant Trade, with a focus on the White-topped Pitcher-plant *Traffic*. Excerpts 17 (2) Available from URL http://www.traffic.org/bulletin/

Rodriguez, J.P., (2000) Impact of the Venezuelan economic crisis on wild populations of animals and plants. *Biological Conservation* 96, 151–159.

Sharma, J., Zettler, L.W., Van Sambeek, J.W., Ellersieck, M.R., Starbuck, C.J., (2003) Symbiotic Seed Germination and Mycorrhizae of Federally Threatened *Platanthera praeclara* (Orchidaceae). *American Midland Naturalist* 149, 104–120

Stubbs, C., (2004) Thefts threat to Waratah's future. *Central Coast Express Advocate* September 23.

Whelan, R.J. & Goldingay, R.L. (1989) Factors affecting fruit-set in *Telopea speciosissima* (Proteaceae): the importance of pollen limitation. *Journal of Ecology* 77, 1123–1134.

Witkowski, E.T. F., Lamont, B.B. & Obbens F.J. (1994) Commercial picking of *Banksia hookeriana* in the wild reduces subsequent shoot, flower and seed production. *Journal of Applied Ecology* 31, 508–520.

Manuscript accepted 16 February 2010

Coastal Sandplain Vegetation at Brisbane Water and Broken Bay – reconstructing the past to plan for the future

Robert Payne[1], Ross Wellington[2] & Michael Somerville[3]

[1]15 Mountain Ash Way Umina Beach 2257 NSW AUSTRALIA, email: ecolsurvey@netspace.net.au
[2]email: rossw@ecoaus.com.au; [3]email: flora@huntercouncils.com.au

***Abstract*:** The vegetation and floristics of the coastal sandplains on the Umina-Woy Woy Peninsula on the northern foreshores of Broken Bay (lat 33° 30' S, long 151° 15' E), 40 km north of Sydney, are described from historical records, sampling of remnants and analysis of regional scale vegetation.

Of the seven vegetation communities described, Umina Coastal Sandplain Woodland (UCSW) was originally the most extensive type of vegetation over the Umina-Woy Woy sandplain and on the seaward side of the Pearl Beach sandplain, and possibly on the sandplains at Patonga and Little Patonga. Characteristic tree species are *Angophora floribunda* and *Eucalyptus botryoides*; the latter appears to be more common at foreshore sites. Close to the sea and in swales at the base of hillslopes, littoral rainforest elements can be present. Patonga may have had significant inclusions of this vegetation.

As a result of clearing for suburban development and its reduction to small remnants, UCSW and Freshwater Wetlands have been listed as an Endangered Ecological Communities under the *NSW Threatened Species Conservation Act*.

A form of the closely-related Sydney Red Gum (SRG) complex occurs on a different SLU on the south-west side of Pearl Beach. A characteristic tree is *Angophora costata.* Site environmental differences between UCSW and the Sydney Red Gum Complex include their occurrence on iron podsols and humus podsols respectively. Regional vegetation classification and analysis shows that these vegetation units are distinctly different from each other. This is supported by historical evidence from surveyor notation on Crown Survey and land subdivision plans.

Originally the Bangalay – Rough-barked Apple Woodland vegetation component of the Umina Woy Woy sandplain was defined by the NSW Scientific Committee for Umina Coastal Sandplain Woodland. Regional analysis now reveals the Red Gum-Red Bloodwood (RGBW) component now merges with this former community. The Pearl Beach vegetation remains separate. A re-definition of UCSW is now required.

Management, particularly of UCSW, currently involves revegetation and regeneration works in the vicinity of existing reserves. However, because the depletion has been so extensive there is further opportunity to decrease the loss by utilising the wide riparian reserves and laneways where mature trees still exist.

A major conservation concern is the modification and loss of the sandplain vegetation, particularly the wetlands. The historical Crown Survey plans highlight the extent of wetlands as an important ecological feature of the original sandplain landscape. The current study estimated that 83% of wetlands and 79% of riparian vegetation has been lost on the Umina-Woy Woy sandplain since European settlement.

***Cunninghamia* (2010) 11(3): 295–317**

Introduction

Extensive coastal sandplains are major landform features behind the main beaches on the northern foreshores of Broken Bay (the estuary of the Hawkesbury-Nepean River) and at the southern end of Brisbane Water. The area is on the Central Coast of New South Wales about 40 km north of Sydney.

Before European settlement began in the 19th Century the sandplains supported a variety of sclerophyll vegetation types including woodlands, wetlands, palm forest, and riparian elements associated with slow flowing stream systems and alluvial fans.

The largest sandplain area, the Umina-Woy Woy sandplain (bounded by Brisbane Water and Blackwall Mountain to the

© 2010 Botanic Gardens Trust

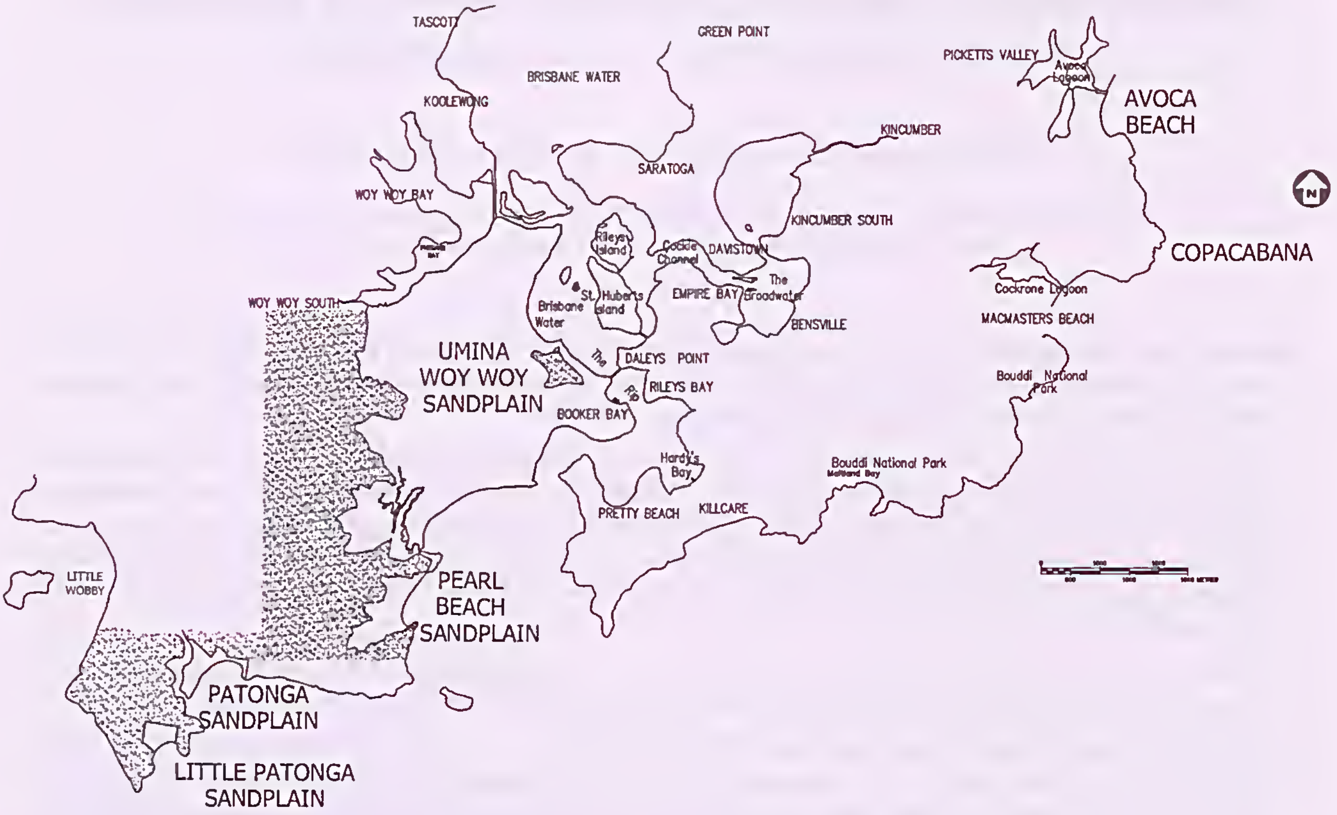


Fig. 1 Location of Brisbane Water sandplain areas to the north of Broken Bay.

north, the Brisbane Water National Park escarpment to the west and Mt Ettalong to the south) once supported more than 1 200 ha of native vegetation (Figure 1). Separate patches of similar habitat occurred at Patonga, Little Patonga and Pearl Beach, and evidence of similar but smaller areas of sandplain vegetation is present at Avoca, Copacabana and Koolewong.

Since European settlement, clearing of vegetation for rural and suburban development, particularly since the 1950s, has left only fragmented and disconnected remnants as 'refugia' scattered through the area. The Umina Coastal Sandplain Woodland Endangered Ecological Community and Sydney Freshwater Wetlands in the Sydney Basin Bioregion Endangered Ecological Community, listed under the NSW *Threatened Species Conservation Act, 1995* provide some legislative cover for some of the small remaining areas of sandplain vegetation. Brisbane Water National Park and some public reserve areas provide additional protection.

Except for brief mentions in the soils-oriented work of Burges & Drover (1953) and Hails (1969), the nature and floristic composition of the Central Coast sandplain vegetation are poorly known. Sandplain vegetation was not recorded adequately in the initial inventory for the Lower Hunter – Central Coast regional mapping (House 2003) and Gosford local government area mapping (Bell 2004), though it has been included in a recent update by Hunter Councils (Somerville 2008).

Griffith et.al. (2000, 2003, 2007) have described the sandplain or 'wallum' vegetation of the NSW North Coast. The sandplain vegetation at Brisbane Water is related to the 'wallum' but does not qualify in the original sense because of the absence of *Banksia aemula* heathlands (it may fit a revised definition, see Griffith et. al. 2003).

Because of the potential changes associated with future developments proposed for the Brisbane Water area coastal sandplains, the few remaining patches of threatened vegetation will require intensive ecological management if they are to survive in the long-term (see Rackham (2006) for similar comments on woodland in Britain). As a basis for management strategies the current study aims to determine the previous vegetation patterns for areas where sandplain vegetation has been almost totally lost, and to identify species and strategies appropriate for restoration projects applicable for areas of cleared land, where rehabilitation of habitat and connection of remnants of native vegetation is required.

Methods

Study Area

The coastal sandplain study area (lat 33° 30' S, long 151° 15' E) encompasses sandplain areas at Umina-Woy Woy, Pearl Beach, Patonga and Little Patonga Beach (in ancient times, all tributaries of the same catchment), and Avoca, Copacabana and Koolewong. Almost all the sandplain vegetation at Patonga, Little Patonga and Avoca has been removed for urban development. At Copacabana and Koolewong only tiny littoral remnants in a very small area of coastal sandplain remain (the Koolewong remnant may be regrowth on redeposited sands from railway construction). At Umina-Woy Woy and Pearl Beach there are more substantial remnants on what were much more extensive and well developed inner and outer beach ridge systems (Figure 1).

The Umina-Woy Woy sandplain is now characterised by a regular pattern of dunes and swales oriented parallel to the beach, which were created by the prevailing south east swell waves. Historically, dune crests were 5–7 m above sea level with swales 1–1.5 m below that level (Hails 1969). These characteristic geomorphic features are evident on historical air photos (Figure 2) and although highly altered by urban development, in some places can still be discerned at groundlevel.

The sandplains of Umina-Woy Woy began to form about 6000 years b.p. as sea levels began to rise (Thom et. al. 1978). The Hawkesbury River system's shelf sand deposits, created by siltation and the presence of the volcanic rock bar off Barrenjoey (White 1999), resulted in the extensive beach dune ridge complex contemporaneous with aggrading of the lower reaches of the Hawkesbury Broken Bay estuary (Albani et al. 1991, 1992).

Radiocarbon dating of shell detritus shows that the Umina-Woy Woy sandplain formed over a period of 4000 years (Thom et. al. 1981). The Umina-Woy Woy Sandplain is the widest in New South Wales, up to 3.7 km wide with an average height of 4 m above sea level. Shoreline displacement per year averaged 0.8 m, although the innermost barrier of 1600 m may have prograded at a rate of 4 m per year. Aeolian reworking of the beach barrier rather than seaward progradation also occurred and parts of the sandplain, where there is a shallow nearshore gradient, probably experienced such a phase (Thom et. al. 1978).

Unleached ridges (i.e. those with iron podzols) are recent (Holocene), which began to form as early as 7000 years BP and older dunes (ie those with humus podzols) are of Pleistocene age. These latter dunes could be recognised by the presence of *Banksia serrata* and *Angophora costata* (Hails, 1969). Referring to the investigations of Burges & Drover (1953) and Hails (1969), Thom et. al. (1978) stated that the whole Woy Woy sandplain is of Holocene age dating from 6240–1380 years BP.

Soil landscape maps by Chapman & Murphy (1989) and Murphy (1993) show the southern part of the Umina-Woy Woy sandplain as part of the Woy Woy Soil Landscape Unit (SLU) (of Recent age) and the north as Tuggerah SLU (aeolian, of Recent and older age). Sandplains at Avoca and Copacabana are also mapped as Woy Woy SLU. Pearl Beach sandplains are mapped as Warriewood SLU (humus podzol soils) and Little Patonga as Cockle Bay SLU (marine and aeolian sands and sandy loams).

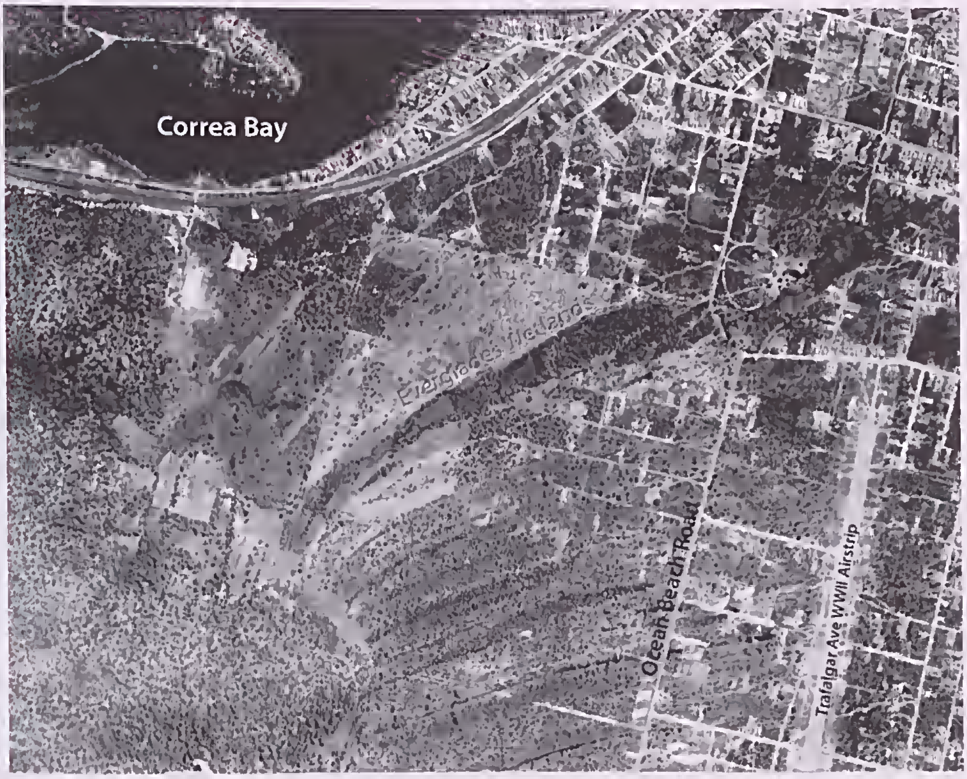


Fig. 2. 1941 aerial photo showing the northern part of the Woy Woy-Umina sandplain in the vicinity of the Everglades Wetland. Note the parallel transgressive dunes supporting woodland vegetation to the south and the more forested vegetation on Aeolian dunes to the north.

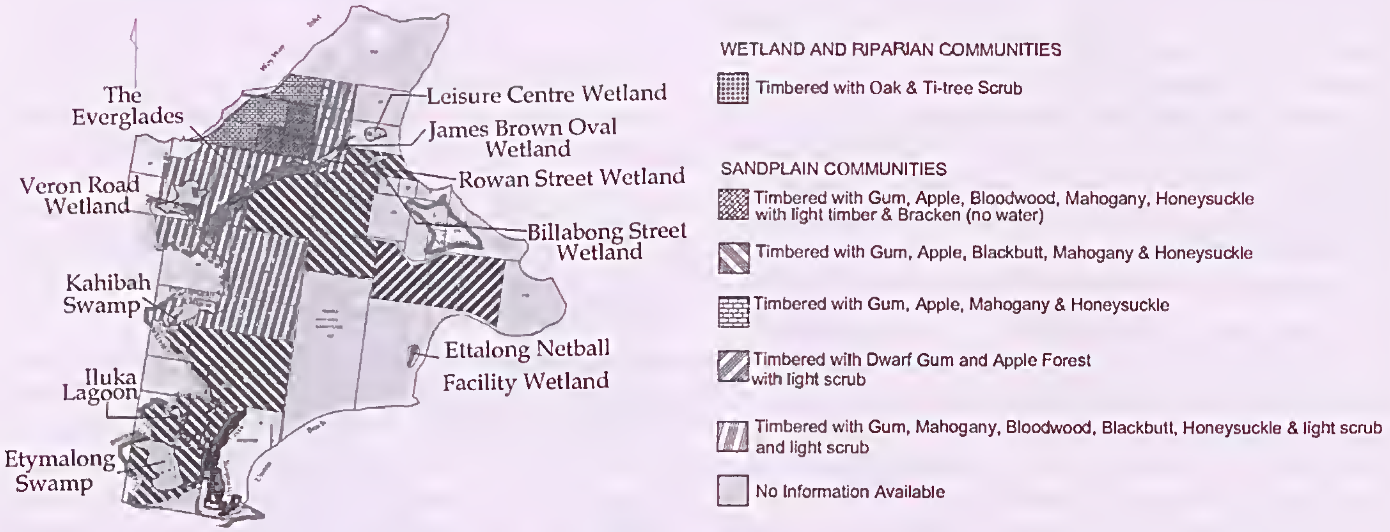

The Everglades
Leisure Centre Wetland
James Brown Oval Wetland
Veron Road Wetland
Rowan Street Wetland
Billabong Street Wetland
Kahibah Swamp
Ettalong Netball Facility Wetland
Iluka Lagoon
Etymalong Swamp
WETLAND AND RIPARIAN COMMUNITIES
Timbered with Oak & Ti-tree Scrub
SANDPLAIN COMMUNITIES
Timbered with Gum, Apple, Bloodwood, Mahogany, Honeysuckle with light timber & Bracken (no water)
Timbered with Gum, Apple, Blackbutt, Mahogany & Honeysuckle
Timbered with Gum, Apple, Mahogany & Honeysuckle
Timbered with Dwarf Gum and Apple Forest with light scrub
Timbered with Gum, Mahogany, Bloodwood, Blackbutt, Honeysuckle & light scrub and light scrub
No Information Available

Fig. 3. Map showing the drainage of the umina Woy Woy sandplain with reference sites cited in the text.

Drainage systems and wetlands

On the Umina-Woy Woy sandplain, the major creek systems, Etymalong Creek, Kahibah Creek and Iluka Creek, drained southward from extensive wetland areas at the base of the Brisbane Water sandstone escarpment to Umina Beach at the foot of Mt Ettalong. These wetlands included those in the southern vicinity of the present day Everglades Golf Course, the Kahibah Swamps (present day remnants near McEvoy Oval and Umina High School), Iluka Lagoon further to the south and the previously extensive Etymalong Swamp wetlands (the last is no longer present to-day). Minor drainage occurred at Ettalong and entered the Brisbane Water estuary almost opposite Half Tide Rocks (today the Ettalong Netball facility). Woy Woy Creek drained northeast and entered Brisbane Water (the head of the creek was probably somewhere near the Community Leisure Centre).

Freshwater wetlands formed the sandplain headwaters of these creeks and were formerly much more extensive. The swamps and lagoons at Woy Woy, near Umina High School, Ettalong and Etymalong are not evident to-day (Figure 3). They have been incrementally reduced or totally destroyed as urbanisation and drainage pressures have occurred over the years.

The Pearl Beach sandplain is dissected by three creeks, one known locally as Green Point Creek, (originally Patonga Creek-see Crown Plan 00092-$_{0719}$) (Figure 8). Pearl Beach Lagoon, the current major water body, lies behind the frontal dune but does not generally support vegetation due to saltwater ingress. In earlier times this lagoon was a much smaller wetland (Crown Plan 00694-$_{2111}$). A swampy area at the rear of the tennis courts near Opal Close shown on early Portion plans (Crown Plan 9822 $_{158}$) no longer exists (Figure 8).

Patonga does not have any drainage line dissecting the sandplain although the sand plain lies alongside Patonga Creek, a major drainage line entering Brisbane Water. There is a small drainage line, which was part of the swale and dune system, at the base of the escarpment. At Little Patonga Beach there are two tributaries that enter the sandplain from the escarpment and in historical times drained into and formed a small wetland. This area was previously known as Spring Bay (Crown Plan 00694 $_{2111}$).

Historical Research

Historical Crown Portion plans, often annotated with surveyor's field notes, are a valuable source of historical information on the pre-European soils, geology and the general vegetation type in an area. Reference trees (ie trees with an offset distance and bearing in order that crown portion corners can be re-established) can be useful because trees are also identified by common name and accurately located.

Crown Portion plans for the Umina-Woy Woy, Pearl Beach and Little Patonga sandplains dating between 1836 and 1943 were examined for vegetation details, reference trees and portion boundaries (no crown plans are available for Patonga). Information from these plans was tabulated and plotted on a cadastral map base, and initial vegetation and reference tree maps were compiled. These vegetation maps showed roughly what type of vegetation occurred in each Crown Portion over the sandplain (Figure 3).

Historical photos at the Gosford City Library and State Library of NSW were examined for supporting information on sandplain and wetland vegetation. Broken Bay 1941 series commonwealth aerial photography was used to identify and confirm vegetation patterns over the sandplain areas, as

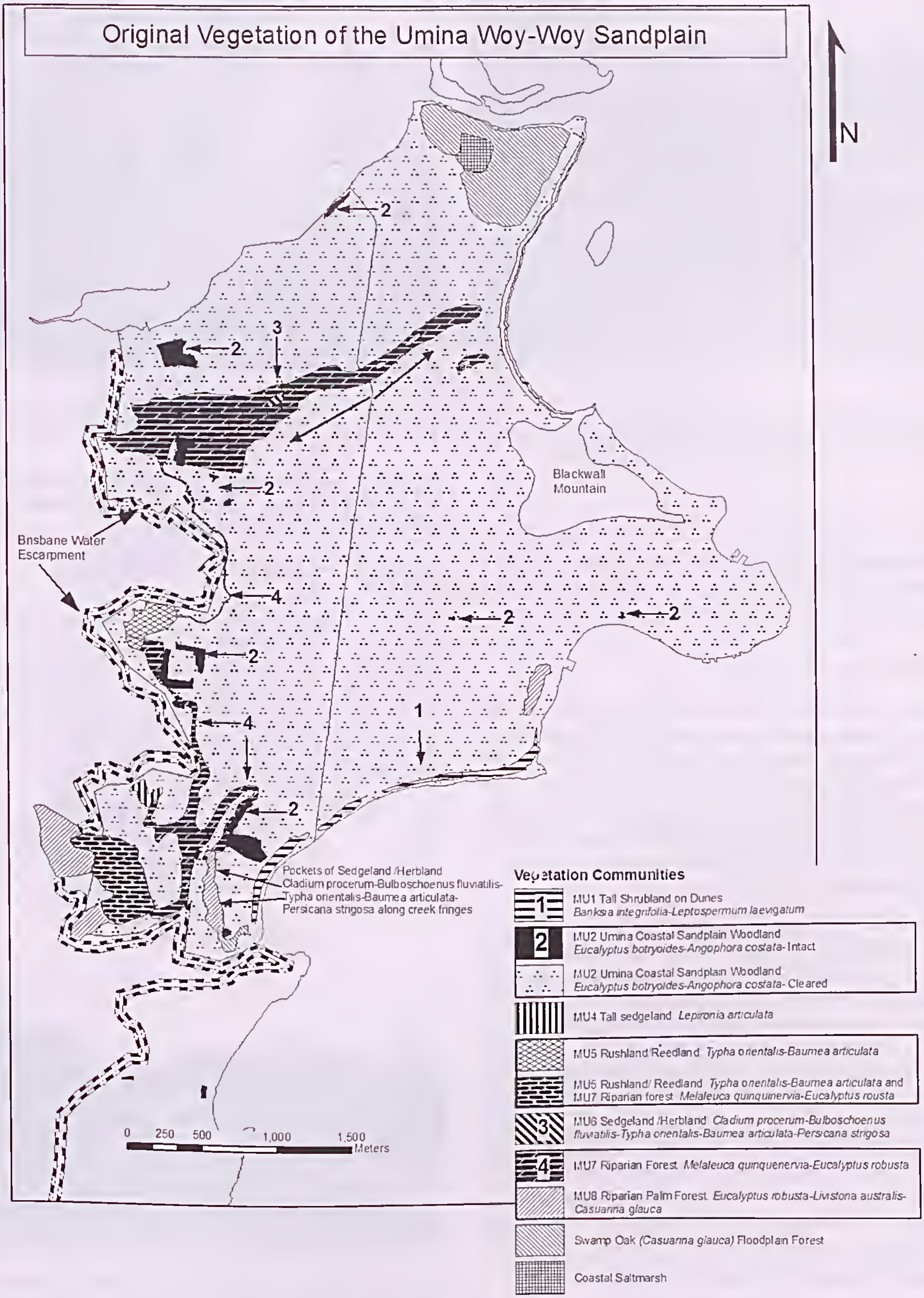

Original Vegetation of the Umina Woy-Woy Sandplain
N
2
3
2
2
Blackwall Mountain
Brisbane Water Escarpment
4
2
2
2
4
1
2
Pockets of Sedgeland /Herbland Cladium procerum-Bulboschoenus fluviatilis-Typha orientalis-Baumea articulata-Persicaria strigosa along creek fringes
0 250 500 1,000 1,500 Meters
Vegetation Communities
1 MU1 Tall Shrubland on Dunes Banksia integrifolia-Leptospermum laevigatum
2 MU2 Umina Coastal Sandplain Woodland Eucalyptus botryoides-Angophora costata- Intact
MU2 Umina Coastal Sandplain Woodland Eucalyptus botryoides-Angophora costata- Cleared
MU4 Tall sedgeland Lepironia articulata
MU5 Rushland/Reedland Typha orientalis-Baumea articulata
MU5 Rushland/ Reedland Typha orientalis-Baumea articulata and MU7 Riparian forest Melaleuca quinquenervia-Eucalyptus robusta
3 MU6 Sedgeland /Herbland Cladium procerum-Bulboschoenus fluviatilis-Typha orientalis-Baumea articulata-Persicaria strigosa
4 MU7 Riparian Forest Melaleuca quinquenervia-Eucalyptus robusta
MU8 Riparian Palm Forest Eucalyptus robusta-Livistona australis-Casuarina glauca
Swamp Oak (Casuarina glauca) Floodplain Forest
Coastal Saltmarsh

Fig. 4. Map of the original vegetation of the Umina Woy Woy sandplain compiled from various sources including early crown survey plans (vegetation for most of the eastern section was not recorded by the early surveyors). Note the extensive wetland systems that have now been almost completely destroyed.

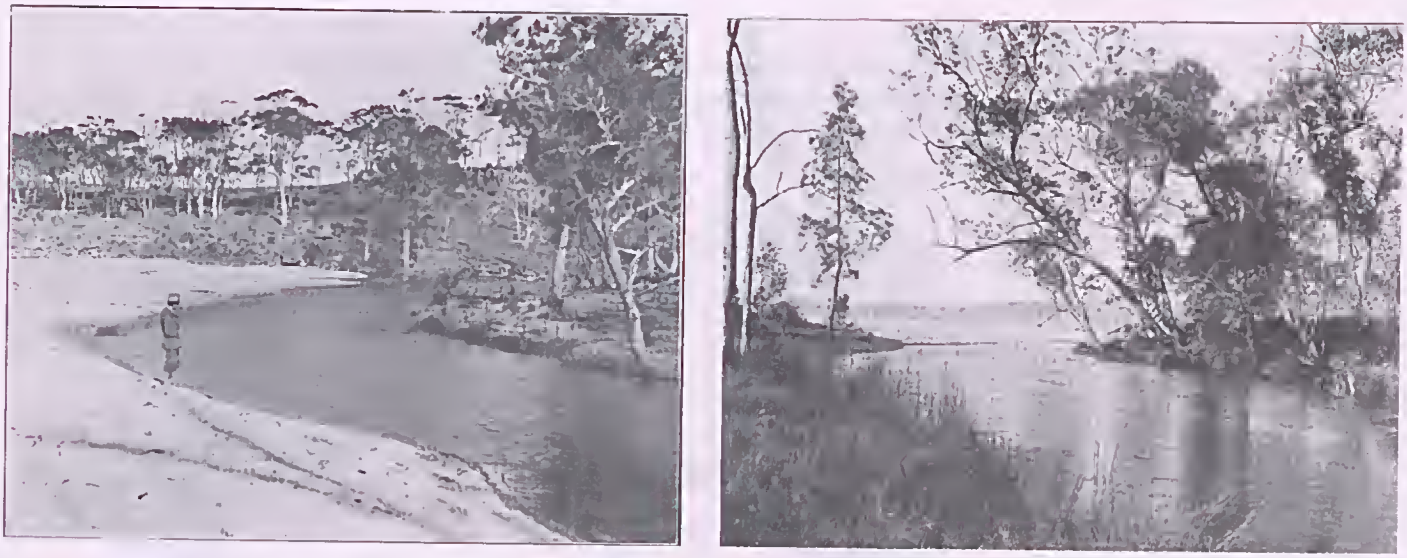


Fig. 5. The vegetation at the mouth of the creek draining the Pearl Beach lagoon showing Swamp Oak, *Casuarina glauca* and saltmarsh, and b) Green Point Creek with Green Point Headland in the background with Spotted Gum, *Corymbia maculata*. Photos taken in 1925. (Reproduced with permission from Gosford City Council).

well as the numerous wetlands that became obvious from the investigation of the historical Portion Plans. Wetlands and drainage lines on each portion were digitised to show location and checked using historical aerial photography.

Field Mapping and Description

The small vegetation remnants that occur throughout Umina-Woy Woy, Patonga and Copacabana were mapped using a GPS or measuring directly from cadastral boundaries. The Pearl Beach sandplain has substantial vegetation cover, and existing remnants were mapped directly using GPS traversing. In all cases the data gathered was tied to the cadastral database using property boundary corners to improve accuracy.

Current floristic data was recorded between 2006–2009 in 400m^2 quadrats in relatively undisturbed vegetation remnants. Descriptions of forest/woodland vegetation communities were prepared following the Sydney Natural Vegetation Study, which includes Little Patonga, Patonga and part of the Umina Woy Woy sandplain (Benson & Howell 1994). All of the vegetation units fit into the Coastal Swamp Forest complex unit (Map Unit 27a) of Benson & Howell (1994). Wetland and riparian vegetation types are based on those of Griffith et al. (2000) for the North Coast For each description, the common name, structure, main species in each strata level, geomorphology/soil landscape unit and occurrence were identified. The descriptions follow Specht (1981) structure classes and for wetlands (Briggs 1981) with supplementary information from Watts (2007).

The 400m^2 quadrat data were also included in the regional analysis for the Central Coast Hunter Great Lakes Region. The dataset used in the final classification results utilised only native species. Braun Blanquet cover/ abundance scores

Table 1. Vernacular names used by surveyors on historical Crown Portion Plans for subdivisions on the Umina-Woy Woy sandplain (Maiden =Maiden 1889)

Common Name	Botanical Name	Source
'Apple'	*Angophora floribunda*	Maiden, local context
'Banksia'	*Banksia serrata*	Maiden
'Blackbutt'	*Eucalyptus pilularis*	Maiden, local context
'Bloodwood'	*Corymbia gummifera*	Maiden, local context
'Bracken'	*Pteridium esculentum*	Maiden, local context
'Burrawang'	*Macrozamia communis*	Aboriginal
'Mahogany'	*Eucalyptus robusta,* *Eucalyptus botryoides*	Maiden
'Honeysuckle'	*Banksia serrata*	Maiden
'Gum'	*Angophora costata*	Local context
'Ti Tree'	*Melaleuca quinquenervia* *Leptospermum polygalifolium*	Maiden, local context

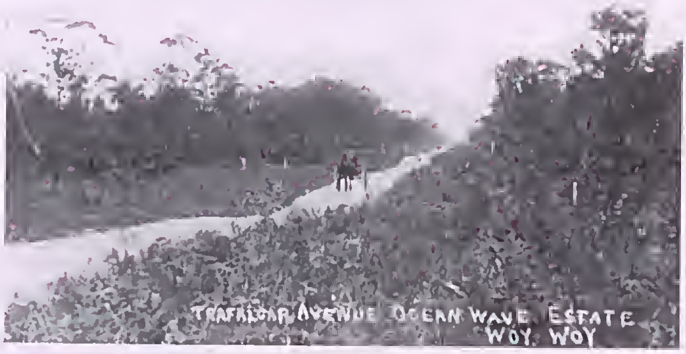


Fig. 6. An early 20th century photo taken between Nelson Street and Britannia Avenue, Umina, showing the sandplain dunes with woodland with thick scrub; *Macrozamia communis* & *Banksia integrifolia* are reasonably identifiable. This vegetation fits descriptions in early Crown surveys. (reproduced with permission from Gosford City Council).

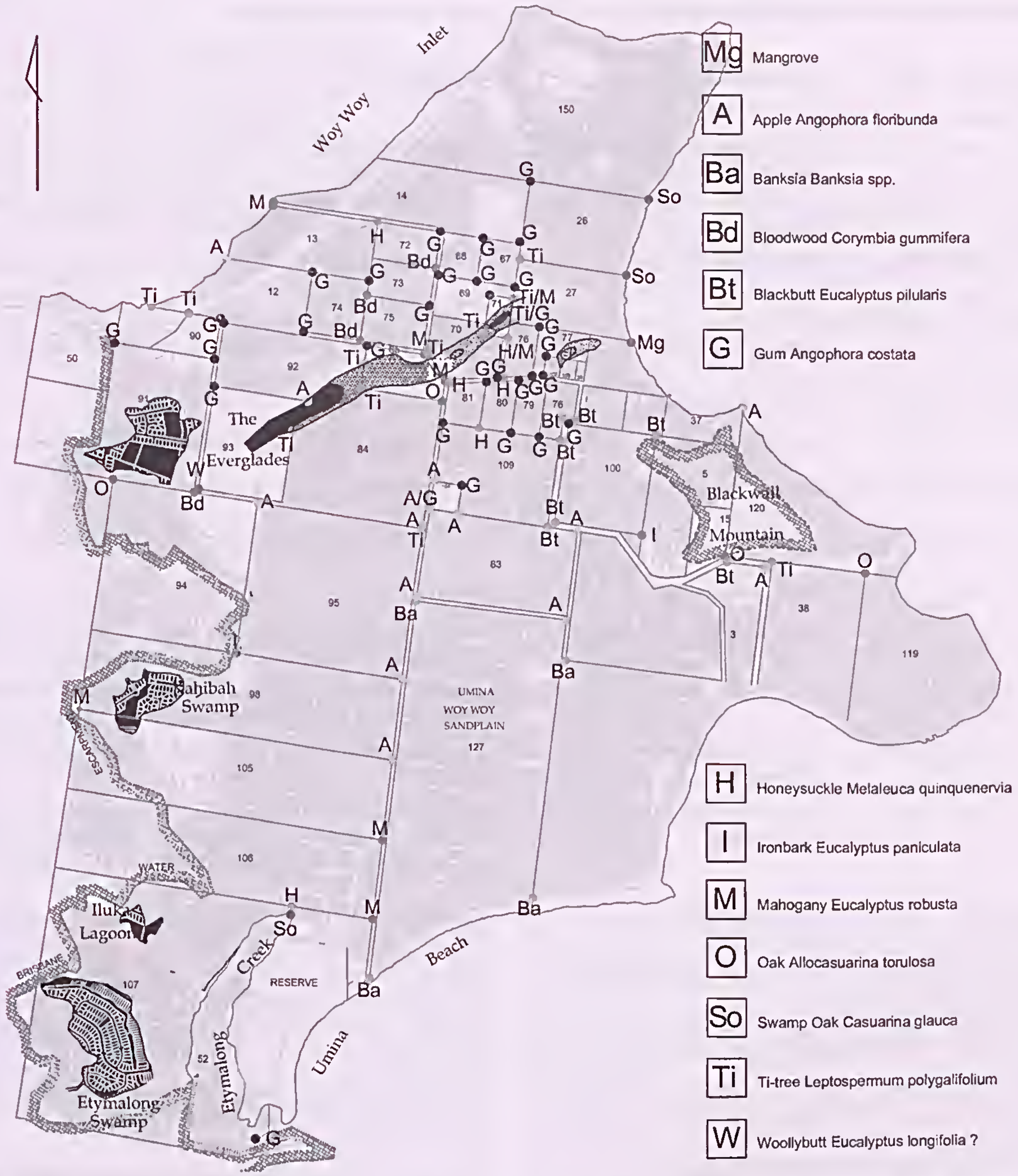

Woy Woy
Inlet
The Everglades
Blackwall Mountain
Kahibah Swamp
Iluka Lagoon
Etymalong Swamp
Etymalong
Creek
RESERVE
Umina
Beach
BRISBANE
WATER
ESCARPMENT
UMINA WOY WOY SANDPLAIN
Mg Mangrove
A Apple Angophora floribunda
Ba Banksia Banksia spp.
Bd Bloodwood Corymbia gummifera
Bt Blackbutt Eucalyptus pilularis
G Gum Angophora costata
H Honeysuckle Melaleuca quinquenervia
I Ironbark Eucalyptus paniculata
M Mahogany Eucalyptus robusta
O Oak Allocasuarina torulosa
So Swamp Oak Casuarina glauca
Ti Ti-tree Leptospermum polygalifolium
W Woollybutt Eucalyptus longifolia ?

Fig. 7. The location of original surveyor reference trees used to relocate portion corners on the Umina Woy Woy sandplain.

were used and the final classification was undertaken using the DOS version of the PATN software package (Somerville 2008).

While it does not support large tracts of natural vegetation, the Umina-Woy Woy sandplain still supports a large number of remnant native trees that have over the years been protected within the large number of public laneways that still exist behind residential properties. Such trees can be used as indicators for the compilation or ground-truthing of vegetation maps. The locations of many of these indicator trees were recorded using a Magellan global positioning system (GPS).

Soil analysis was undertaken using standard laboratory techniques to determine iron, organic matter and pH. Two soil samples from the soil profile of iron podzols on the Umina Woy Woy sandplain and two samples of humus podzols on the Pearl Beach sandplain were taken. Each soil sample was collected using a hand auger and was measured in the laboratory for pH, iron and organic matter.

The pH was measured by placing 100mL of wet soil into measuring cylinders with deionised water and, after vigorous shaking, measured with a water analyser.

Organic matter was calculated using the percent organic matter and combustion method. Approximately 10g of soil

Table 2. Reference trees and vegetation details shown on Crown Grants – Parish Of Patonga

Portion No.	Date	Plan	Reference Trees	Description
UMINA–WOY WOY SANDPLAIN				
3,4 & 5	1881	717_{2111}	Gum, Apple, Ti-tree, Oak, Blackbutt & Banksia	Dwarf Gum & Apple Forest with scrub
12, 13 & 14	1892	3322_{2111}	Ti-tree, Gum, Apple, Honeysuckle, Mahogany and Oak	Gum, Apple, Mahogany, Honeysuckle, Bloodwood & Scrub
26	1837	95_{719}	Gum, Oak & Ti-tree	No details provided
27	1839	$105A_{719}$	Oak	No details provided
28, 29, 30, 31, 32 & 33	1895	3424_{2111}	Gum & Bloodwood	Timbered with Gum, Mahogany, Bloodwood, Honeysuckle & light scrub.
34, 35, 36, 37	1867	124_{719}	No detail provided	No detail provided
38	1835	65_{719}	No detail provided	No detail provided
50	1871	979_{1501}	Ironbark, Apple & Oak	No detail provided
52	1872	33_{2111}	Gum, Ti-tree, Woollybutt, Swamp Oak	Thick scrub. Timbered with Oak and Ti-tree.
66	1894	3360_{2111}	Apple & Blackbutt	Swamp
67, 68, 69 & 70	1875	3423_{2111}	Gum, Mahogany & Ti-tree	Timbered with Gum, Mahogany, Bloodwood, Blackbutt, Honeysuckle & light scrub. Lagoon & Ti-tree swamp. (Wetlands on Pts. 70 & 71)
71	1875	3425_{2111}	Gum, Ti-tree & Honeysuckle	Timbered with Gum, Mahogany, Bloodwood, Blackbutt, Honeysuckle & light scrub. Lagoon & Ti-tree swamp.
72, 73, 74 & 75	1895	3422_{2111}	Gum, Mahogany, Bloodwood & Honeysuckle	Timbered with Gum, Apple, Mahogany, Bloodwood, Honeysuckle & light scrub.
76, 77, 78, 79, 80 & 81	1895	3426_{2111}	Gum, Ti-tree, Blackbutt & Honeysuckle	Part Pt. 77 shows a swamp with Ti-tree. The remainder shows timbered with Gum, Apple, Blackbutt, Mahogany and Honeysuckle. Part Pt. 78 with Honeysuckle & thick scrub. (Wetland shown on Pt. 77)
83, 84 & 109	1895	3428_{2111}	Gum, Blackbutt, Apple, Ti-tree & Oak	Timbered with Gum, Apple, Blackbutt, Mahogany and Honeysuckle. Light scrub. Part Pt. 84 shows lagoon.
85	1895	3429_{2111}	Oak, Ti-tree, Gum & Mahogany	Most of Pt. swampy surrounded by Gum, Apple, Ti-tree Mahogany, Blackbutt & Honeysuckle. (Wetland shown).
90	1895	3431_{2111}	Gum, Ti-tree, Honeysuckle, Mahogany, Gum, Apple & Turpentine	Timbered with Gum, Mahogany, Blackbutt, Bloodwood, Ti-tree & Honeysuckle
91,92 & 93	1895	3430_{2111}	Ti-tree, Apple, Gum, Woollybutt, Bloodwood, Mahogany & Oak	Timbered with Gum, Bloodwood, Blackbutt, Mahogany & Honeysuckle. Part Pt. 91 has Swampy Ti-tree and Pt. 93 has creek & lagoon with Ti-tree & light scrub.
94, 95 & 98	1896	3432_{2111}	Apple & Ironbark	Timbered with Gum, Mahogany, Blackbutt, Honeysuckle & Ti-tree with Banksia scrub. Part Pt. 94 with Ti-tree watercourse. Pt. 98 shows Kahibah Lagoon.
100	1876	318_{2111}	Gum, Blackbutt and Ironbark	No details provided
104	1895	3360_{2111}	Blackbutt & Ironbark	
105,106 & 107	1895	3433_{2111}	Apple, Mahogany & Honeysuckle	Thick Honeysuckle & Banksia scrub; Honeysuckle & Ti-tree. Creek shown as swampy watercourse. Timbered with Gum, Apple, Mahogany & Blackbutt just west of Ettymalong Creek. Ettymalong Ck. Shown as swampy watercourse AND Etymalong Swamp shown.
119		B 648 old roll		missing
121	1836	93_{719}	Banksia and Apple	No details provided
125	1831	43_{719}	No details provided	Mangrove flat on Pelican Island only
154	1908	4392_{2111}	Apple & Gum	Timbered with Apple, Gum, Blackbutt, Mahogany & Honeysuckle
496	1977	$N9063_{2111}$	No detail provided	No detail provided

PEARL BEACH				
8	1837	92_{719}	No details provided	No details provided
9	1840	158_{645}	No detail provided	No detail provided
96	1873	79_{2111}	Gum & Bloodwood	No detail provided
97	1873	79_{2111}	Gum & Bloodwood	No detail provided
101	1876	$N319_{2111}$	Bangalow & Gum	Wetland shown.
132 & 152	1932	9822_{158}	Gum & Bloodwood	Heavily timbered with gum, Bloodwood, Honeysuckle, Peppermint, Mahogany, Ironbark & thick scrub. Wetland shown.
159		6493_{2111}	No detail provided	Heavily timbered with gum, Bloodwood, Honeysuckle, Peppermint, Mahogany, Ironbark & thick scrub.
172		6693_{2111}	No detail provided	Heavily timbered with gum, Bloodwood, Honeysuckle, Peppermint, Mahogany, Ironbark & thick scrub.
179	1921	5884_{2111}	Oak stump & Apple stump	No detail provided
215 & 216	1932		Mahogany, Gum & Peppermint	Heavily timbered with gum, Bloodwood, Honeysuckle, Peppermint, Mahogany, Ironbark & thick scrub.
337	1943	$N7569_{2111}$	Ironbark, Turpentine & Gum	Timbered with Gum, Bloodwood, Blackbutt, Honeysuckle, Oak & undergrowth.
PATONGA				
Public Reserve and lots		No details provided	No details provided	No details provided
LITTLE PATONGA				
1 & 2	1880	694_{2111}	Apple, Bloodwood, Honeysuckle, Oak, Gum & Turpentine	Moderately timbered with gum and apple tree. Wetland shown.

was placed into crucibles, which had been cleaned, dried and weighed. Each crucible was placed in a muffle surface on a stainless steel tray and heated to 550°C and allowed to stay in the furnace for 1.5 hours. After combustion the crucibles were removed from the furnace and allowed to cool before they were reweighed. The weight loss, due to combustion, was used to calculate the percentage organic matter in the soil.

Iron was tested using the DTPA method. Ten grams of air dried soil was shaken with with 20Ml of DTPA extractant for two hours. The leachate was filtered and iron measured in the filtrate by atomic absorption spectrophotometry (Lindsay & Norvell 1978).

Results

Historical Research and Field Mapping

Most historical sources give common or vernacular names rather than scientific names to vegetation and plant species. For example early Crown Portion plan vegetation notes refer to "Honeysuckle, Ti-tree Swamp" or "Ti-tree Scrub". Individual reference trees are variously described as "Honeysuckle, Ti-tree" and "Banksia".

The botanical identity of these names was confirmed as far as possible using 19th Century literature together with likelihood of occurrence in the sandplain ecological context (Table 1). Maiden (1889) indicates Honeysuckle referred to *Banksia serrata* whilst Ti-tree referred to either *Melaleuca quinquenervia* or *Leptospermum polygalifolium*. Field checking of notes on the early plans for the Everglades, Billabong Street (Portion 77) and within the lower reaches of Etymalong Creek suggests both "Ti-tree Swamp" and "Ti-tree scrub" refer to *Melaleuca quinquenervia* even though the latter community does not occur as a "scrub". Wetlands are variously described either as "lagoon", Ti-tree swamp, Ti-tree watercourse or swampy watercourse.

Umina – Woy Woy Sandplain

The pattern of distribution of vegetation over the Umina – Woy Woy sandplain compiled from surveyor's field notes on historical Crown plans (Table 2) indicates a number of variants with different combinations of canopy species, as well as previously unrecognised areas of riparian and wetland vegetation. "Gum, Apple, Blackbutt, Mahogany and Honeysuckle" (interpreted respectively as *Angophora costata, Angophora floribunda, Eucalyptus pilularis, Eucalyptus robusta* and *Banksia serrata*) covered extensive areas of the sandplain. This was associated with an understorey of thick or light scrub or a "Honeysuckle" and "Banksia scrub".

The original historical reference trees used to locate portion corners on the Umina Woy Woy sandplain (Figure 7) include 13 species, the most common being Gum (assumed to be *Angophora costata)* followed by Apple (*Angophora floribunda)*, Blackbutt (*Eucalyptus pilularis)* and Bloodwood (*Corymbia gummifera)*. The clustering of historical reference trees indicated as "Gum" (presumably *Angophora costata*) north-west, north and south of Everglades (Figure 7), suggest this area supported *Angophora costata* – *Corymbia gummifera* Red Gum-Red Bloodwood (RGRB) forest (part of Coastal Dune forest of Benson & Howell 1994). The surveyor records also indicate that this area supported "Gum, Bloodwood, Blackbutt, Mahogany and Honeysuckle" (*Angophora costata, Corymbia gummifera, Eucalyptus pilularis, Eucalyptus robusta, Banksia serrata)*. The understorey comprised "Ti-tree" (probably in swales) and "Banksia scrub" (probably on ridges).

A general view of the sandplain vegetation along a transect running inland from Umina Beach is provided in Burges and Drover's (1952) work on soil podzol development, done before the extensive suburban development of the 1960s and 70s. They reported that *Leptospermum laevigatum – Banksia integrifolia* occurred as a frontal dune community about 90 m wide behind Umina Beach. Behind this *Eucalyptus botryoides* was present, gradually merging with *Angophora floribunda* at 140 m from the beach where iron podzol soils occur. This vegetation is readily observed on historical 1941 aerial photographs as open woodland. Hails (1969) recorded that unleached sands of the Umina-Woy Woy Sand plain (i.e. iron podzols) were dominated by a scrub of *Leptospermum laevigatum, Angophora floribunda* and *Banksia integrifolia* with "woodland of Bangalay *Eucalyptus botryoides* and dominated by ferns and Bracken"".

Burges and Drover (1953) report that around Woy Woy and Ettalong *Eucalyptus pilularis* (Blackbutt) was common (large remnant trees can still be seen today), and that *Corymbia gummifera* Red Bloodwood and *Eucalyptus botryoides* Bangalay occurred in the vicinity of Woy Woy, Ettalong, and Blackwall. *Angophora floribunda* (Rough-barked Apple) was more common at the southern end of Umina Beach.

Changes in soil type are correlated with the change in vegetation. Where soils change to humus podzols *Angophora costata* replaced *Angophora floribunda*. The change occurred between 1800–2700 m from the beach where the soil B-horizon becomes well developed (Burges & Drover 1953). Hails (1969) recorded that the humus podsolized ridges of the Umina-Woy Woy Sand plain supported a "dune heath and scrub dominated by *Banksia* and *Angophora*. The Red Gum Red Bloodwood Forest, *Angophora costata* – *Corymbia gummifera* dominates this latter soil habitat.

Burges & Drover (1953) and Hails (1969) postulated that the difference between the iron podzols and humus podzol soil types on the Umina Woy Sand plain can be attributed to the age and consequently the development of the soil profile and the height of the watertable. Watertable depths, at least on humus podzols at Pearl Beach are variable and localised and being sometimes only found at depth. Those on the Umina Woy Woy sandplain tend to be found at a shallower depth.

Comparison with current vegetation

Descriptions of current Sandplain Vegetation Communities and component species based on data from existing vegetation remnants are given in Appendices 1 and 2.

Overall the early vegetation descriptions and remnant vegetation suggests that dune vegetation on the Woy Woy-Umina sandplain commonly included a range of canopy trees. The combination of *Angophora floribunda* (Rough-barked Apple), with *Eucalyptus botryoides* (Bangalay) in foreshore sites, as described in the Final Determination of the NSW Scientific Committee and listed as the Umina Coastal Sandplain Woodland EEC (UCSW) appears to have been predominant over the south east half of the sandplain.

Vegetation on the northern half of the sandplain appears to have been Red Gum-Red Bloodwood forest, (areas at Hillview St are now regarded as included within UCSW). Red Gum-Red Bloodwood forest RGRB with *Angophora costata, Corymbia gummifera, Eucalyptus pilularis* and *Banksia serrata* occurred between Kahibah Swamp and the Everglades Golf Course, and on aeolian soils north of the Everglades (Figure 3). Part of this vegetation type was recorded as "Dwarf Gum and Apple Forest" on Portions 3, 4 & 38 and probably extended further south into Portion 126, where windswept conditions predominate.

Fieldwork indicates that the UCSW includes more littoral species than previously recognised. At Umina Beach there are two very large *Ficus rubiginosa* at the rear of the foredune with stands of *Livistona australis* Cabbage Tree Palm, *Ficus coronata* Sandpaper Fig and *Alphitonia excelsa* Red Ash; other littoral species in remnants are found along the foreshore from Woy Woy to Blackwall. Early photos of the Woy Woy foreshore support this view (Government Tourist Bureau 1907, p. 17). Similar littoral elements are also present at Patonga and Copacabana.

Soil differences between UCSW and RGBW communities on the Umina – Woy Woy sandplain

Identification between these two vegetation types UCSW and RGBW may be difficult because of the floristic continuity across the sandplain, and the small size and degraded condition of existing remnants mean that the characteristic species diversity is not well represented at any particular site.

The vegetation patterns on the Umina-Woy Woy sandplain, as indicated in the historical survey plans, support Burges and Drover's (1953) vegetation types related to soil leaching processes and height above sea level. Both Burges & Drover

(1953) and Hails (1969) recognised that the transgressive dunes gradually progress from an iron podzol to a humus podzol as dune age increases across the sandplain. Iron podzols are related to the younger Holocene dunes and humus podzols to the older Holocene dunes.

Humus podzols develop as humus leaches down through the soil profile and consolidates just above a water table, where a dense organic pan (Coffee Rock) can form. As the humic acids increase and move down through the soil profile, the calcium carbonate, derived from shells and other crustacean material are dissolved over time. This leaching results in the older sands having iron 'B' horizons at a greater depth and a deeper 'A' horizon of pale grey sand. Where the water table is encountered the iron goes into solution and the organic matter accumulates as "Coffee Rock".

Table 3. Comparison of iron (Fe) and pH values for soil types with UCSW vegetation (on iron podzols) and SRG vegetation (on humus podzols) using Paired T-Test.

	Results	Mean	SD	t	Sig
UCSW pH	5.85; 5.82	5.84	0.02	8.7	0.07
SRG pH	4.8; 5.11	5.43	0.36		
UCSW Fe (ppm)	507; 331	419	124.5	5.2	0.12
SRG Fe (ppm)	51; 21	36	21.2		
UCSW om (%)	0.23; 0.12	0.18	0.07	-2.8	0.22
SRG om (%)	0.42; 0.21	3.27	2.42		

Chemical analysis of the soils associated with the two vegetation types (UCSW & Pearl Beach SRGF) show that the iron content (mean= 419 ppm v 36 ppm) may be used to define the difference. There may be a possibility of using percent organic matter (0.17% v 3.26 %), but the number of readings available are too low to make a significant comparison. A paired T-Test (Table 3) showed no significant difference between the means of the available results at this stage.

Although the soil types differ, there is a high degree of floristic continuity between the two sandplain vegetation types, where small remnants are involved. This situation is also observed at Copacabana where the UCSW vegetation variant (Bell 2004) extends up onto the Narrabeen countryrock. Similarly at Pearl Beach the SRG Complex occurs on Warriewood, Erina and Watagan SLU's. The floristic variation over the Umina-Woy Woy and Pearl Beach sandplains is perhaps not unusual; similar trends have also been shown in the "Kwongan" sandplain area of Western Australia (Pate & Beard 1984) suggesting that sandy soils have a low level of edaphic control over understorey plant species distribution.

Pearl Beach Sandplain

In 1906 Minard Crommelin *"sailed down to Pearl Beach in a cedar boat.... The beach was so beautiful with a great number of Cabbage Tree palms, growing along the little creeks and up the valleys and hillsides"* (Webb 1994). Timber-getting was a working enterprise in the early 20th Century. One visitor remembers her father removing Turpentine from Pearl Beach. Logs were stacked and left floating in the water, attached to piles from the beach (P. Westlake pers. com. 2005)

The Pearl Beach sandplain is still densely treed and partly densely vegetated. The vegetation map (Figure 8) is based primarily on existing vegetation remnants, as historical surveyor reference trees and vegetation descriptions are poorly documented except for the south western corner of the sandplain. The lagoon at Pearl Beach was originally only a small soak (crown plan 319 $_{2111}$) but was greatly enlarged, prior to 1941, as landowners removed sediment to raise the levels of their adjoining land (P. Westlake, pers comm.). In the 1960s a resident remembered the boulder-strewn section of the creek at the rear of the Pearl Beach sandplain colonised with large colonies of *Pyrrosia rupestris* (Rock Felt Fern) and pockets of *Livistona australis* (Cabbage Tree Palm).

There are differences between vegetation at Pearl Beach and Umina-Woy Woy. Riparian vegetation at Pearl Beach is mainly palm- dominated; at Umina-Woy Woy although isolated areas of similar vegetation occurred (eg at the rear of Etymalong Swamp, the downstream section of Etymalong Creek and the Ettalong Netball Facility) riparian vegetation was mainly Ti-Tree *(Melaleuca quinquenervia)*. The main type of sandplain vegetation at Pearl Beach is similar to Sydney Red Gum complex but with *Xanthorrhoea arborea* (Grass Tree) dominated understorey. This type of vegetation is not found at Umina-Woy Woy except in Burrawang Reserve where Murphy (1993) suggests that sands are Aeolian (Tuggerah SLU).

Patonga, Avoca, Copacobana and Koolewong sandplains

Historically neither vegetation nor reference trees were recorded for the Patonga sandplain. Most of the original vegetation had been cleared by the 1940s (Anon 1945). The littoral form of UCSW is still present as a tiny remnant at the southern end of Patonga; it appears to extend to the dune foreshore in historical photos. At Little Patonga Beach, the extent of vegetation clearance is evident on the 1941 air photos.

The Avoca Beach UCSW vegetation has been cleared. Copacabana still supports a narrow remnant dominated by littoral rainforest elements with *Angophora floribunda* and *Eucalyptus botryoides*. The sandplain remnant at Koolewong railway station appears to have re-established on sand altered during railway construction in the 1880s. It is dominated by *Angophora floribunda* and currently (2009) supports a Bandicoot population.

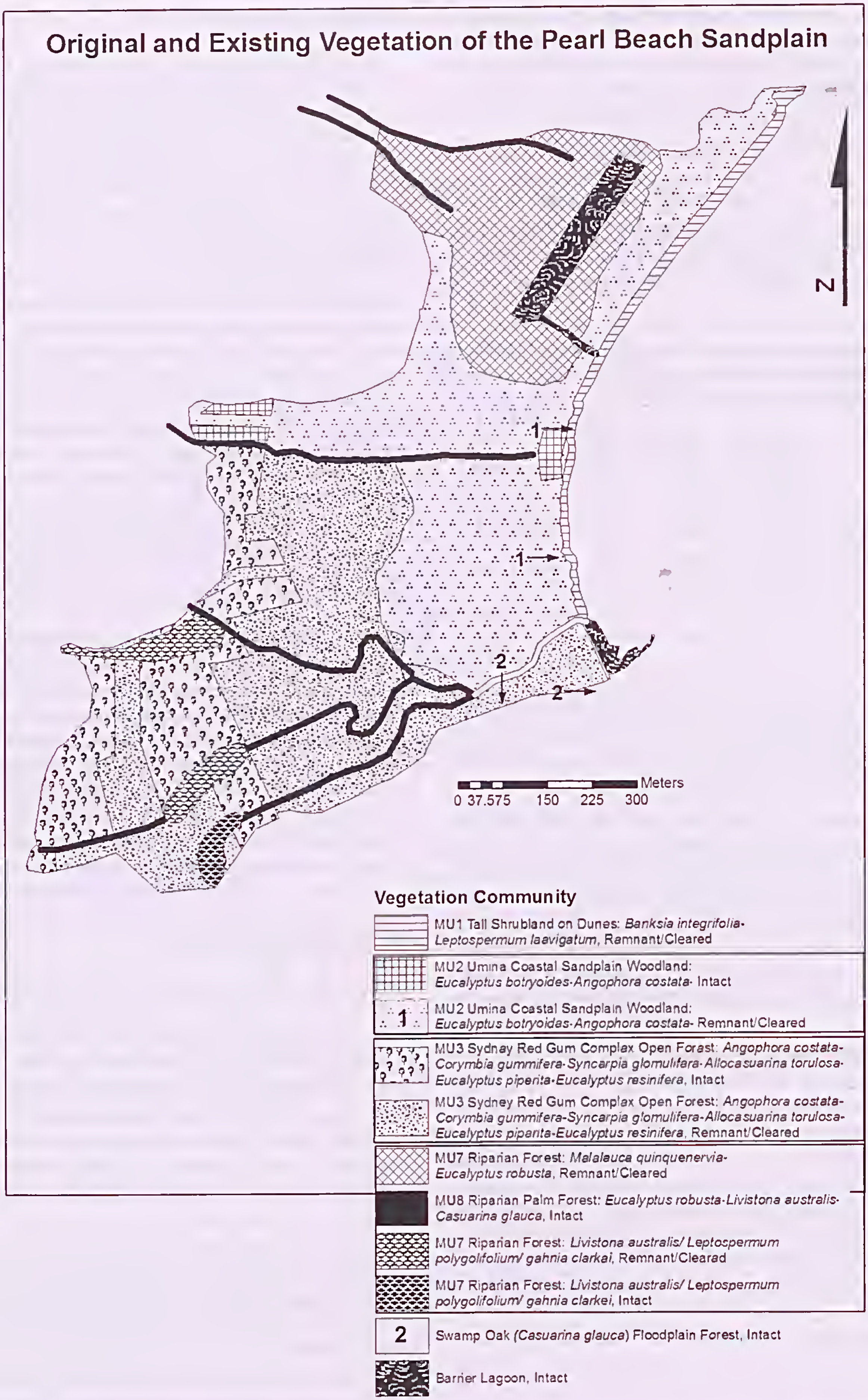

Original and Existing Vegetation of the Pearl Beach Sandplain
N
1
1
2
2
Meters
0 37.575 150 225 300
Vegetation Community
MU1 Tall Shrubland on Dunes: Banksia integrifolia-Leptospermum laavigatum, Remnant/Cleared
MU2 Umina Coastal Sandplain Woodland: Eucalyptus botryoides-Angophora costata- Intact
1 MU2 Umina Coastal Sandplain Woodland: Eucalyptus botryoidas-Angophora costata- Remnant/Cleared
MU3 Sydnay Red Gum Complax Open Forast: Angophora costata-Corymbia gummifera-Syncarpia glomulifara-Allocasuarina torulosa-Eucalyptus piperita-Eucalyptus resinifera, Intact
MU3 Sydney Red Gum Complax Open Forest: Angophora costata-Corymbia gummifera-Syncarpia glomulifera-Allocasuarina torulosa-Eucalyptus piparita-Eucalyptus resinifera, Remnant/Cleared
MU7 Riparian Forest: Malalauca quinquenervia-Eucalyptus robusta, Remnant/Cleared
MU8 Riparian Palm Forest: Eucalyptus robusta-Livistona australis-Casuarina glauca, Intact
MU7 Riparian Forest: Livistona australis/ Leptospermum polygolifolium/ gahnia clarkai, Remnant/Clearad
MU7 Riparian Forest: Livistona australis/ Leptospermum polygolifolium/ gahnia clarkei, Intact
2 Swamp Oak (Casuarina glauca) Floodplain Forest, Intact
Barrier Lagoon, Intact

Fig. 8. Map of Pearl Beach showing original and existing vegetation compiled primarily from field survey of existing remnants.

Loss of Wetland areas

Early survey records show extensive natural swamp vegetation once existed along the drainage lines on the Umina-Woy Woy sandplain. The innermost beach ridges enclosed swamps with *Phragmites australis* reeds, sedges and *Melaleuca* (Swamp Paperbark or Ti-tree), *Eucalyptus robusta* (Swamp Mahogany) and *Casuarina glauca* (Swamp Oak).

Prior to 1990 Iluka Lagoon was mostly dominated by *Lepironia articulata*, whilst *Baumea articulata* covered the majority of Kahibah Swamp and much of Etymalong Swamp and Etymalong Creek with patches in the Pearl Beach Lagoon (pers. obs). Etymalong Swamp also supported pockets of Swamp Mahogany *Eucalyptus robusta* and Broad-leaved Paperbark *Melaleuca quinquenervia*. Up until 2000 the Everglades Lagoon supported more diverse wetland vegetation with *Melaleuca quinquenervia* forest and sedgelands/ herblands *of Bolboschoenus fluviatilis, Cladium procerum* and *Persicaria strigosa* (Swamp Dock) (pers. obs.).

Most of the natural swamp vegetation has been destroyed by extensive drainage alteration and reclamation works (Table 4). For example the Veron Road (Kahibah Swamp) and Ettalong Wetlands had been mostly reclaimed by 1941, and during the 1960s the drainage lines were deepened, widened and straightened with a cut-off channel constructed on Etymalong Creek (McLauren Road), with the beginning of residential influx. Reclamation of remaining wetlands occurred in 1985–95 despite many local residents and Gosford City Council making a strong stand against the residential development over the Etymalong Swamp (Bruce Kerr Pty Ltd vs Gosford City Council, 1985; 1988).

Table 4. Estimated extent of loss of Coastal Freshwater Wetlands and Riparian Forest on the Umina Woy Woy sandplain since European settlement

?=Losses likely but difficult to determine

Location	Original Area (ha)	Area lost	Percent Lost
COASTAL FRESHWATER WETLANDS			
Etymalong Swamp	18.07	18.07	100
Iluka Lagoon	1.89	0.58	31
Veron Road Wetlands	12.17	11.73	96
Kahibah Swamp	6.33	4.36	69
The Everglades	4.71	?0	? 0
James Brown Oval Wetland	0.30	0.30	100
Rowan Street Wetland	0.30	0.30	100
Billabong Street Wetlands	0.31	0.31	100
Ettalong Netball Facility	2.50	2.50	100
Woy Woy Leisure Centre	2.63	2.63	100
Total	49.21	40.78	83
RIPARIAN FOREST			
Etymalong Creek	9.82	3.12	32
Iluka Creek	1.11	1.11	100
Kahibah Creek	1.91	1.91	100
Kahibah Swamp/Veron Road Wetlands	3.49	3.49	100
The Everglades/Roberts Park	17.60	15.84	90
Rowan Street/Woy Woy Community Centre	2.60	2.60	100
James Brown Oval	0.98	0.98	100
Woy Woy Leisure Centre	2.15	2.15	100
Total	39.76	31.20	78

Although Iluka Lagoon has not been reclaimed, it has suffered dramatically from the effects of upstream development through siltation, which has virtually caused the local extinction of *Lepironia articulata*. In the 1980s, prior to upstream development, this wetland was more or less a pristine tall sedgeland (and the only wetland of its type on these sandplains), but today (2009) this freshwater wetland supports mostly weeds, and needs recovery action.

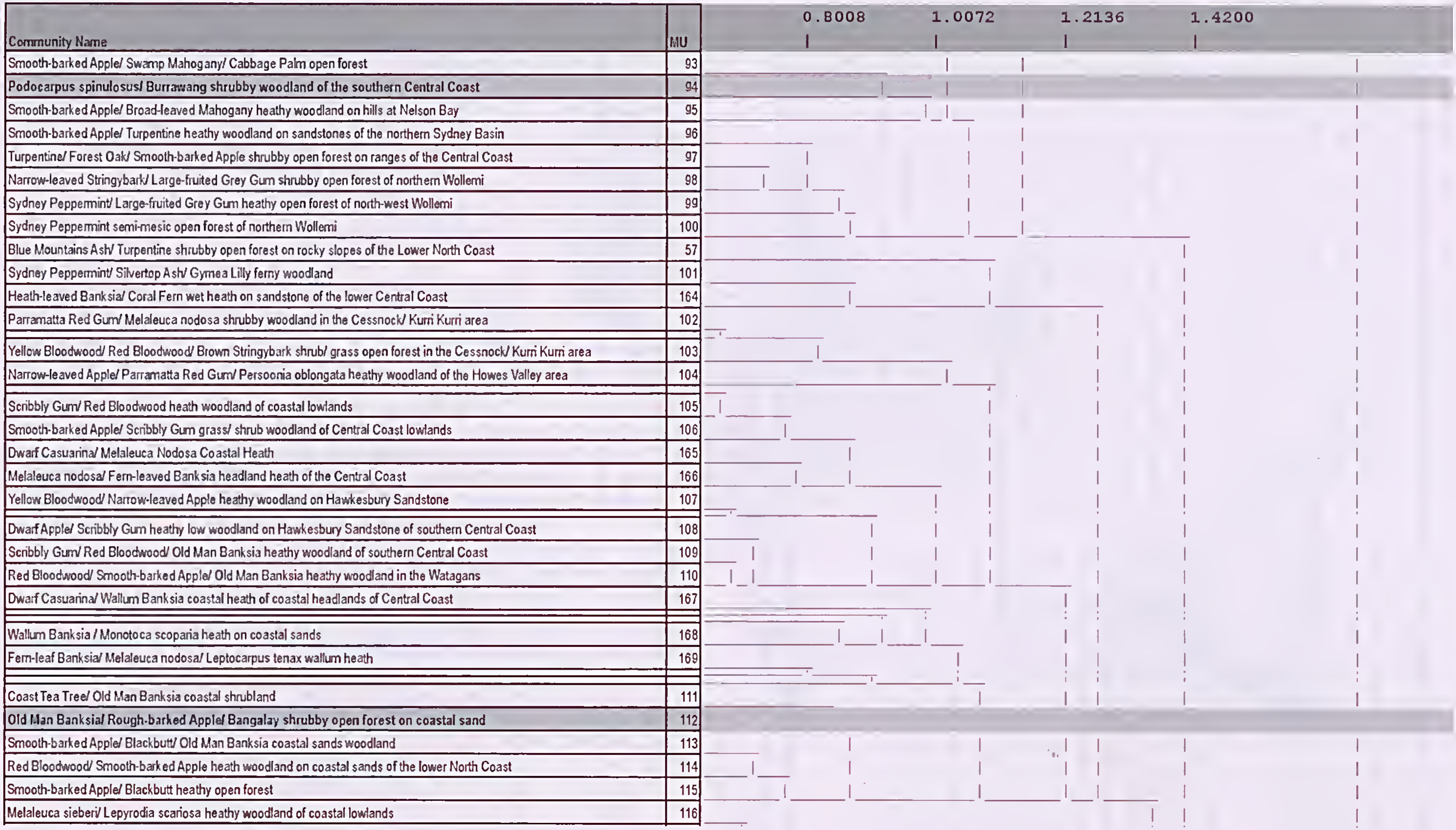
Within drainage lines and Kahibah Swamp, changes in local hydrology caused by reclamation are causing Cumbungi, *Typha orientalis*, to displace *Baumea articulata* and *Blechnum indicum*. Some of these changes have coincided with excavation of creeks to remove the aquatic vegetation and move storm runoff away more quickly to reduce the risk of flooding to private property. About 83% of wetlands and 79% of riparian vegetation has been lost on the Woy Woy Umina Peninsula alone (Table 4).

Regional floristic analyses

Whilst it may be difficult to determine the difference between these two main vegetation types, UCSW and RGBW described above, based on visual assessment and analysis at a local scale, statistical analyses was used at a more regional scale.

In a recent regional vegetation classification based on an analysis of over 4600 sites across the Hunter, Central and Lower North Coast region, a total of 21 sites in of the Umina community and 9 in the Pearl Beach community were included. (Somerville 2008). Sites on the Umina -Woy Woy sandplain all merge together as one unit but are separate from those at Pearl Beach. These units lie within a broader group of sclerophyllous open forest, woodland and heath communities mostly occurring on coastal sands and sandstones, but the dendrogram (Figure 9) shows these communities are relatively widely separated based on floristics sampled at the regional scale. It should be noted here that not all sites included in the original classification of the Umina and Pearl Beach communities were used in the regional classification due to the process used to include or exclude sites from that analysis.

The Umina -Woy Woy sandplain community is equivalent to the Old Man Banksia/ Rough-barked Apple/ Bangalay shrubby open forest on coastal sand (MU 112) identified in the regional classification. The UCSW sites occur mainly



Community Name	MU
Smooth-barked Apple/ Swamp Mahogany/ Cabbage Palm open forest	93
Podocarpus spinulosus/ Burrawang shrubby woodland of the southern Central Coast	94
Smooth-barked Apple/ Broad-leaved Mahogany heathy woodland on hills at Nelson Bay	95
Smooth-barked Apple/ Turpentine heathy woodland on sandstones of the northern Sydney Basin	96
Turpentine/ Forest Oak/ Smooth-barked Apple shrubby open forest on ranges of the Central Coast	97
Narrow-leaved Stringybark/ Large-fruited Grey Gum shrubby open forest of northern Wollemi	98
Sydney Peppermint/ Large-fruited Grey Gum heathy open forest of north-west Wollemi	99
Sydney Peppermint semi-mesic open forest of northern Wollemi	100
Blue Mountains Ash/ Turpentine shrubby open forest on rocky slopes of the Lower North Coast	57
Sydney Peppermint/ Silvertop Ash/ Gymea Lilly ferny woodland	101
Heath-leaved Banksia/ Coral Fern wet heath on sandstone of the lower Central Coast	164
Parramatta Red Gum/ Melaleuca nodosa shrubby woodland in the Cessnock/ Kurri Kurri area	102
Yellow Bloodwood/ Red Bloodwood/ Brown Stringybark shrub/ grass open forest in the Cessnock/ Kurri Kurri area	103
Narrow-leaved Apple/ Parramatta Red Gum/ Persoonia oblongata heathy woodland of the Howes Valley area	104
Scribbly Gum/ Red Bloodwood heath woodland of coastal lowlands	105
Smooth-barked Apple/ Scribbly Gum grass/ shrub woodland of Central Coast lowlands	106
Dwarf Casuarina/ Melaleuca Nodosa Coastal Heath	165
Melaleuca nodosa/ Fern-leaved Banksia headland heath of the Central Coast	166
Yellow Bloodwood/ Narrow-leaved Apple heathy woodland on Hawkesbury Sandstone	107
Dwarf Apple/ Scribbly Gum heathy low woodland on Hawkesbury Sandstone of southern Central Coast	108
Scribbly Gum/ Red Bloodwood/ Old Man Banksia heathy woodland of southern Central Coast	109
Red Bloodwood/ Smooth-barked Apple/ Old Man Banksia heathy woodland in the Watagans	110
Dwarf Casuarina/ Wallum Banksia coastal heath of coastal headlands of Central Coast	167
Wallum Banksia / Monotoca scoparia heath on coastal sands	168
Fern-leaf Banksia/ Melaleuca nodosa/ Leptocarpus tenax wallum heath	169
Coast Tea Tree/ Old Man Banksia coastal shrubland	111
Old Man Banksia/ Rough-barked Apple/ Bangalay shrubby open forest on coastal sand	112
Smooth-barked Apple/ Blackbutt/ Old Man Banksia coastal sands woodland	113
Red Bloodwood/ Smooth-barked Apple heath woodland on coastal sands of the lower North Coast	114
Smooth-barked Apple/ Blackbutt heathy open forest	115
Melaleuca sieberi/ Lepyrodia scariosa heathy woodland of coastal lowlands	116

Fig. 9. Dendrogram showing regional vegetation units recognised in PATN analyses.

on the Umina sandplain on Quaternary (on both Tuggerah and Woy Woy SLUs) sands at an average elevation of 2 m. The diagnostic canopy species of MU 112 were *Angophora floribunda* (67% of 21 sites), *Eucalyptus botryoides* (43%), *Corymbia gummifera* (33%), with *Allocasuarina littoralis* occurring at over 85% of sites. Diagnostic understorey species included *Banksia serrata* (95%) and *Macrozamia communis* (91%), along with *Glochidion ferdinandi* and *Monotoca elliptica*.

The Pearl Beach SRG community equates to *Podocarpus spinulosus*/ Burrawang shrubby woodland of the southern Central Coast (MU 94), which is also rare at the regional scale. The Pearl Beach SRG community is restricted within the regional classification to a group of sites at the rear of the Pearl Beach sandplain on both Quaternary sands (Warriewood SLU) and Triassic sandstones (Erina and Watagan SLU's) at an average elevation of 31 m. The diagnostic canopy species of MU94 were *Angophora costata* (78% of 8 sites), *Corymbia gummifera* (78%), *Livistona australis* (78%), *Syncarpia gummifera* (67%), *Eucalyptus piperita* (44%) and *Allocasuarina torulosa* (33%). *Macrozamia communis* (100%) and *B. serrata* (67%) are again prominent in the understorey; however *Elaeocarpus reticulatus* (100%), *Podocarpus spinulosus* (89%), *Pultenaea flexilis* (89%) and *Xanthorrhoea arborea* (78%) are also diagnostic features of this community.

Beyond the Umina Woy Woy sandplain the nearest communities in the regional classification are those typically occurring on Quaternary sands, mainly coastal shrubland, woodland and heath communities, including Wallum communities found further north near Newcastle and the lower North Coast. All the related communities have a number of factors in common, including the occurrence on low lying sands and the presence of *Banksia aemula*. On the other hand, the Pearl Beach SRG community appears to have affinities to more hinterland communities of woodland and open forests, on Triassic sandstones of the Sydney Basin.

Discussion

Historical Crown Portion plans, early aerial photography and early photos were found to be useful in determining pre-settlement patterns in sandplain vegetation. Although not all Crown plans could be located, an overall picture of the original vegetation pattern emerged combining current remnants with historical data.

Before being cleared for suburban development, vegetation over the Umina-Woy Woy sandplain was Umina Coastal Sandplain Woodland (UCSW) in the south merging with Red Gum Red Bloodwood (RGBW). Similar vegetation extended onto the seaward side of the Pearl Beach sandplain and possibly on the sandplains at Patonga and Little Patonga.

Within UCSW, littoral elements are present adjacent to the sea; Patonga may have had significant inclusions of this vegetation. Swale vegetation also has mesophyllous elements such as *Ceratopetalum apetalum* and *Callicoma serratifolia*.

The Bangalay-Rough-barked Apple Woodland is the vegetation component defined originally by the NSW Scientific Committee for Umina Coastal Sandplain Woodland. Regional analysis now reveals the RGBW component, located north of the Everglades, merges with this former community, but the Pearl Beach vegetation will always be separate. A re-definition of UCSW is now required.

Given the very large extent of vegetation loss on these sandplains (Table 4), this is a good reason for re-establishing increased areas of Sandplain Woodland and riparian and wetland vegetation on the Umina-Woy Woy sandplain. The species lists and descriptions provided in this paper will assist the re-establishment programs. A particular effort should be made to re-establish some areas of lost UCSW vegetation; there are many remnant trees that once formed part of this vegetation community that could be incorporated into and re-established as a viable reserve, in line with the new proposed re-development strategy currently under review by the NSW Government. For example the early records show *Eucalyptus pilularis* (Blackbutt) was previously widespread on the sandplains, but is now almost locally extinct. It requires re-establishing in areas where it used to grow using seed from the few existing over mature trees that still survive near Blackwall Mountain. Since many of drainage reserves are very wide and the numerous rear laneways still exist there is capacity for further restoration. Identifying areas along the wide drainage reserves and any laneways as connecting corridors for wildlife, should be part of the planning process during redevelopments on the Umina Woy Woy sandplain areas.

Management issues for sandplain vegetation include continued revegetation and regeneration of the existing wetlands, including the small remnant in Billabong Street Woy Woy . Priority projects should be

(1) the recovery of *Lepironia articulata* at Iluka Lagoon because this species has almost but disappeared locally.

(2) to increase the extent of UCSW vegetation at the reserve in Dulkara Avenue by placing additional mulch from UCSW trees, 300 mm thick, over the existing grass to allow the UCSW vegetation to expand

(3) Undertake weed removal/bush regeneration at the McEvoy Oval UCSW remnant

(4) Cover the exotic grass cover at Umina Oval with 300 mm thick UCSW mulch to allow expansion of the native vegetation.

Improvements to riparian management began when management practices changed in the late 1990s. The introduction of 'threatened' species legislation such as the *NSW Threatened Species Conservation Act* and the listing of Freshwater Wetland and Umina Coastal Sandplain Woodland as "endangered ecological communities" has played a major role in highlighting vegetation in need of restoration. Local Land Care groups and professional bush regeneration companies under the direction of Gosford City Council began to restore these vegetation communities. Mechanical excavation of riparian aquatic vegetation has ceased and only selected trees are now removed from banks to reduce the flood risk to private property. There is now a concentrated effort to restore and manage vegetation at Etymalong Creek, Iluka Lagoon, Umina Oval, Kahibah Creek, the Everglades, Umina High School, Blackwall, Pearl Beach and the Hillview Street and Burrawang Reserves. Management plans are available for most of these sites. Some small billabong areas, left isolated by the previous straightening of Etymalong and Iluka Creeks, have also been protected and are being restored. This invaluable work has had a major impact in restoring native vegetation and eradicating weeds.

Acknowledgements

The following people provided advice and information to help bring this study together; Doug Benson, Barbara Wiecek (Royal Botanic Gardens Sydney), Alison Fairweather (NSW Department of Lands), Chris Coombs, Geoff Potter and Larry Melican (Gosford City Council), Phil Westlake, Kay Williams (Pearl Beach Residents), Kristy Woolcock (bush regeneration), Helen Dickinson (for historical research) and an anonymous reviewer.

References

Albani, A.D., Rickwood, P.C., Neilson,L. & Lord, D. (1991) Geological and Hydrodynamic Conditions in Broken Bay, New South Wales. *University of NSW Centre for Marine Science Technical Contribution Series* No 1.

Anon (1945) *Patonga Beach*. Picture held at the Mitchell Library. Call No SV/30.

Bell, S. (2004) The vegetation of the Gosford Local Government Area. Gosford City Council.

Benson, D.H. & Howell, J. (1994) The natural vegetation of the Sydney 1: 100 000 mapsheet. *Cunninghamia* 3 (4): 679–1003.

Briggs, S. (1981) Freshwater Wetlands in *Australian Vegetation. Ed. R.H. Groves*. (Cambridge University Press).

Bruce Kerr P/L VS Gosford City council (AUSTLII WEB SITE)

Burgess, A. & Drover, D.P. (1952) The rate of podzol development in the sands of the Woy Woy district, NSW. *Australian Journal of Botany* 1: 83–94.

Chapman, G.A. & Murphy, C.L. (1989) Soil Landscapes of the Gosford and Lake Macquarie 1: 100 000 Sheet. Soil Conservation Service of NSW.

Government Tourist Bureau (1907) Tourists Handbook of the Hawkesbury River and North Coast District. Copy held in Gosford City Library.

Griffith, S.J., Wilson, R. & Maryott-Brown, K. (2000) Vegetation and flora of Booti Booti National Park and Yahoo Nature Reserve, lower North Coast of New South Wales. *Cunninghamia* 6(3): 645–716.

Griffith, S.J., C. Bale, P. Adam, & R. Wilson (2003) Wallum and related vegetation on the NSW North Coast: description and phytosociological analysis. *Cunninghamia* 8(2): 202–252.

Griffith, S.J. & Wilson R. (2007) Wallum on the Nabiac Pleistocene barriers, lower North Coast of New South Wales. *Cunninghamia* 10(1): 93–111.

Hails, J.R. (1969) The origin and development of the Umina-Woy Woy beach ridge system, Broken Bay New South Wales. *Australian Geographer* 11:1–12.

Herfort, V. (No Date) Reflections at Woy Woy, NSW. Early picture held at Mitchell Library. Call No SV* Photo 5.

House, S. (2003) Revised Vegetation Survey, Classification and Mapping. Lower Hunter and Central Coast Region. Lower Hunter and Central Coast Regional Environmental Strategy.

Lindsay W.L. & Norvell. W.A. (1978) Development of a DTPA soil test for zinc, iron, manganese and copper. *Journal of the Soil Science Society of America* 42: 421–428.

Maiden, J.H. (1889) *The Useful Native Plants of Australia*. Facsimile Edition Compendium 1975).

Murphy, C.L. (1993) Soil Landscapes of the Gosford and Lake Macquarie 1; 100 000 Sheet. Soil Conservation Service of NSW.

Pate, J.S. & Beard, J.S. (1984) *Kwongan Plant Life of the Sandplain*. (University of Western Australia Press. Nedlands Western Australia).

Rackham, O. (2006) *Woodlands*. (Harper Collins).

Somerville, M. (2008), *Hunter, Central & Lower North Coast Vegetation Classification & Mapping Project: Volume 1: vegetation classification technical report*, report prepared by HCCREMS/ Hunter Councils Environment Division for Hunter–Central Rivers Catchment Management Authority, Tocal, NSW.

Specht, R.L. (1981) Foliage Projection Cover and Standing Biomass in *Vegetation Classification in Australia*. Eds. A.N. Gillison & D.J. Anderson. CSIRO and ANU.

Thom, B.G., Polach, H.A. & Bowman, G.M. (1978) Holocene Age Structure of Coastal Sand Barriers in New South Wales, Australia. University of NSW Faculty of Military Studies Department of Geography.

Thom, B.G., Bowman, G.M., Gillepsie, R. Polach, H.A. & Barbetti (1981). Progradation histories of sand barriers in New South Wales. *Search* 12 (9): 323–325.

Watts, D.C. (2007) *Dictionary of Plant Lore*. (Elsevier).

Webb, J. (1994) *Pearl Beach Legacy. The Story of Minard Crommelin– Visionary*. (Surrey Beatty & Sons).

White, M.E. (1999) The Quaternary History of Broken Bay, New South Wales in *Reading the Rocks*. (Simon & Schuster).

Manuscript accepted 16 February 2010

Appendix 1

Descriptions of current Sandplain Vegetation Communities based on data from existing vegetation remnants, observations and historical sources

Coastal Holocene Dunes

Tall Shrubland: *Banksia integrifolia – Leptospermum laevigatum*

Structure: Tall shrubland

Habitat: Holocene foredunes exposed to strong sea borne winds.

Distribution: The best example is at Patonga but also occurs behind Ocean Beach, Umina Beach and Ettalong.

Floristic composition: *Banksia integrifolia* Coast Banksia and *Leptospermum laevigatum* Coastal Ti-tree are the main canopy species with a subcanopy of *Monotoca elliptica*, *Pittosporum undulatum*, *Clerodendrum tomentosum*, *Alphitonia excelsa* and *Breynia oblongifolia*. Understorey species include *Lomandra longifolia*, *Hydrocotyle bonariensis* and *Hibbertia scandens*.

Related mapping units: MU 34 Coastal Sand Wallum Woodland Heath (House 2003); E50a Coastal Sand Foredune Scrub (Bell 2004).

Umina Coastal Sandplain Woodland (UCSW) Woodland: *Eucalyptus botryoides – Angophora floribunda* (Fig. 10)

Structure: Woodland with shrubby and cycad understorey

Habitat: Holocene Sands (Woy Woy SLU) on soils with iron podzols.

This is Umina Coastal Sandplain Woodland and for the purpose of this study includes littoral elements found in swales, because they are not able to be mapped across a disturbed landscape. It also includes the vegetation on aeolian sands (Tuggerah SLU).

Distribution: Mostly cleared, now only found as remnants at Umina Oval, Pearl Beach, Blackwall, Patonga and Copacabana. Mostly on Holocene sediments (Woy Woy SLU). On Aeolian sand (Tuggerah SLU) in Burrawang Reserve (Hillview Street, Woy Woy).

Floristic composition: The canopy is dominated by *Angophora floribunda* (Rough-barked Apple) and *Eucalyptus botryoides* (Bangalay) with a low tree layer of *Allocasuarina littoralis* and *Banksia integrifolia subsp. integrifolia* close to the foreshore. On foreshore sites and in swales at the base of hillslopes, littoral rainforest elements with *Ficus rubiginosa* as a canopy tree with sub canopy trees such as *Acmena smithii*, *Callicoma serratifolia*, *Ceratopetalum apetalum*, *Clerodendrum tomentosum*, *Elaeocarpus reticulatus*, *Euroschinus falcata*, *Glochidion ferdinandi*, *Guioa semiglauca*, *Livistona australis*, *Schizomera ovata* and *Leptospermum polygalifolium*, can be present.

In other locations *Eucalyptus botryoides* and *Angophora floribunda* extended almost to the foreshore along with *Casuarina glauca* (Herfort, no date). *Banksia integrifolia*, *Breynia oblongifolia* and *Exocarpus cupressiformis* make up a second mid stratum layer together with other littoral species such as *Pittosporum revolutum*, *Synoum glandulosum*, *Acronychia oblongifolia*, *Rapanaea variabilis*, *Rhodomyrtus psidioides* and *Pittosporum multiflorum* (prev. Citriobatus pauciflorus) at Copacabana. The groundlayer is generally comprised of *Macrozamia communis*, *Lepidosperma longitudinale*, regenerating littoral species and ferns such as *Pteridium esculentum*, *Pellaea falcata*, *Doodia aspera* and *Adiantum hispidulum*. *Cissus antarctica* and *Eustrephus latifolius* are the main climbers.

Aeolian dune ridges on the Tuggerah SLU occur at the northern end of the sandplain in Woy Woy. These sand ridges have more of a forest vegetation (see Fig. 2) dominated by *Angophora costata* and *Corymbia gummifera* (RGBW). Understorey trees are *Banksia serrata*, *Allocasuarina littoralis* and groundplants include *Acacia suaveolens*, *Banksia serrata*, *Breynia oblongifolia*, *Lomandra longifolia* and *Pteridium esculentum*.

In the sand dune swales here, woodland is dominated by *Angophora floribunda*, *Banksia serrata*, *Eucalyptus robusta*, and *Melaleuca quinquenervia*. The understorey plants mainly comprise *Banksia serrata*, *Monotoca elliptica*, *Exocarpus cupressiformis*, *Angophora floribunda*, *Allocasuarina littoralis*, *Dodonaea triquetra*, *Acacia longifolia* subsp. *longifolia*, *Macrozamia communis*, *Lomandra longifolia* and *Pteridium esculentum*.

The only area on the Umina-Woy Woy sandplain where this aeolian dune and swale vegetation remains is the Burrawang Reserve (Hillview Street, Woy Woy). It is the most important reserve on the sandplains for this reason. Although floristically and visually this vegetation looks similar to the Sydney Red Gum complex at Pearl Beach, it lacks the distinctive *Xanthorrhoea* Grass Tree understorey and the co-dominants of *Eucalyptus resinifera* and *Syncarpia glomulifera*.

Vegetation on coastal aeolian dunes is incorporated with Umina Coastal Sandplain Woodland in the regional PATN analysis.

Related mapping units: MU 33 Coastal Sand Apple Blackbutt Forest (House, 2003); Umina Sands Coastal Woodland E 33bi (Bell, 2004)

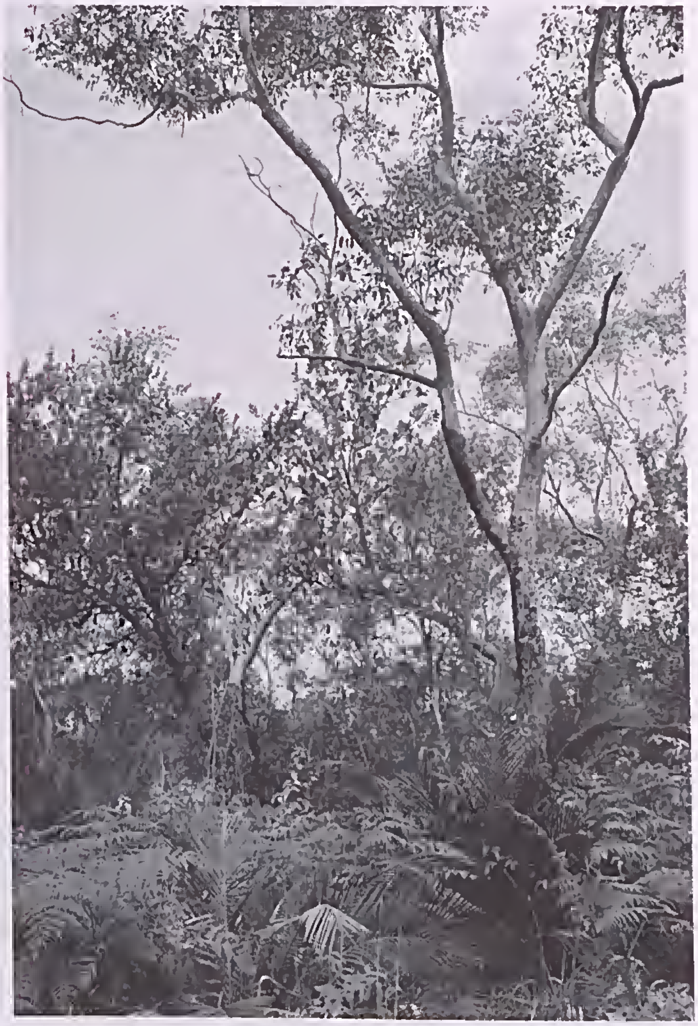


Fig. 10. Woodland dominated by *Angophora floribunda* and *Eucalyptus botryoides* with *Banksia serrata* as a sub-dominant. *Macrozamia communis* is conspicuous in the ground layer

Sydney Red Gum Complex (SRGC)

Open Forest: ***Angophora costata – Corymbia gummifera – Syncarpia glomulifera – Allocasuarina torulosa – Eucalyptus piperita – Eucalyptus resinifera*** (Fig.11)

Structure: Forest with a shrubby, cycad and grass tree understorey

Habitat: found on humus podzols on Holocene Sands (Warriewood SLU). Riparian elements along narrow riparian habitats or alluvial fans occur on both humus podzols and iron podzols on Holocene Sands (Warriewood and Woy Woy SLUs). The sandplain sites merge with those found on the Triassic Hawkesbury Sandstones.

Distribution: Pearl Beach in Brisbane Water National Park, the Crommelin Native Arboretum and the Crommelin Biological Research Station.

Riparian remnants only found as small pockets at the rear of Pearl Beach, at the rear of the Pearl North Estate (which was previously part of the Etymalong Swamp) and at the Crommelin Native Arboretum and Crommelin Research Station. It once also occurred at the Ettalong Netball Facility Wetland

Floristic Composition: *Angophora costata* Sydney Red Gum, *Corymbia gummifera* Red Bloodwood, *Syncarpia glomulifera* Turpentine, *Allocasuarina torulosa* Forest Oak, *Eucalyptus piperita* Sydney Peppermint *and Eucalyptus resinifera* Red Mahogany are all canopy dominants. The lower tree layer is made up of *Allocasuarina torulosa, Syncarpia glomulifera and Banksia serrata.* A number of species make up the mid stratum layers such as *Synoum glandulosum, Leptospermum polygalifolium, Pultenaea daphnoides, Persoonia levis, Elaeocarpus reticulatus, Dillwynia floribunda, Pultenaea flexilis, Dodonaea triquetra* and *Podocarpus spinulosus.* The ground layer is always distinctive and dominated by *Macrozamia communis* and *Xanthorrhoea arborea. Lomandra longifolia, Themeda australis* and *Entolasia stricta* also occur.

In riparian locations remnant palms suggest *Livistona australis,* Cabbage Tree Palm was a tall emergent with canopy trees of *Eucalyptus piperita, Sydney* Peppermint, *Syncarpia glomulifera* Turpentine and *Eucalyptus paniculata* Grey Ironbark. Understorey trees included *Ceratopetalum apetalum, Trochocarpa laurina, Persoonia pinifolia, Livistona australis, Omalanthus populneus* and *Leptospermum polygalifolium.* Where swampy conditions occurred large trees of *Leptospermum polygalifolium* were present with a dense canopy and with an equally dense sedgeland of *Gahnia clarkei* beneath. Ferns included *Hypolepis muelleri* and *Calochlaena dubia.* At the rear of the previous Ettymalong Swamp pockets of dense palm forest occur with little or no understorey.

Related mapping units: Not shown by House (2003); Hawkesbury Apple Peppermint Forest e25 of Bell (2004)

Coastal Freshwater Swamps

Tall Sedgeland: *Lepironia articulata*

Structure: Dense cover of tall sedges up to 2 m high.

Habitat: Deep acid waters over Holocene sands (Woy Woy SLU).

Distribution: This type of reedland was found only in Iluka Lagoon. Prior to the 1990s the lagoon was in fairly good condition but since the development around Homan Close, it has become degraded through siltation. Despite concentrated efforts by the Iluka Landcare Group to revive the vegetation, it has almost become locally extinct.

Floristic composition: Mainly occurs as a monospecific stand of *Lepironia articulata.* Currently very disturbed and in need of recovery.

Related mapping units: MU 33 Coastal Sand Apple Blackbutt Forest (House 2003; Umina Lepironia Sedgeland E45 of Bell (2004).

Rushland/Reedland: *Typha orientalis – Baumea articulata*

Typha orientalis is now dominant in part of the Kahibah Swamp wetland with pockets of *Hypolepis muelleri* and *Persicaria strigosa,* with occasional trees of *Melaleuca quinquenervia* and *Glochidion ferdinandi.* This vegetation has recently colonised the northern end of the wetland. Residential subdivision has caused silt to enter which was later colonised by *Typha orientalis.* Although a native species Typha is not retained by the Authorities because it increases the risk of flooding.

Prior to 1990 this wetland was dominated by *Baumea articulata* with *Blechnum indicum* and *Hypolepis muelleri* and the previous vegetation persists at the southern end of the wetland where the impacts are less, although originally this area appeared to be mainly open water (**Figure 12).** Small pockets of *Melaleuca quinquenervia* and *Eucalyptus robusta* are now colonising the western edge on silt entering the wetland through drainage pipes.

This type of vegetation along with Common Reed, *Phragmites australis,* was also present in the meandering Etymalong, Kahibah and Iluka Creeks.

Related mapping units: MU 40 Swamp Oak Rushland Forest by House (2003) and Coastal Sand Swamp Forest E37ai of Bell (2004).

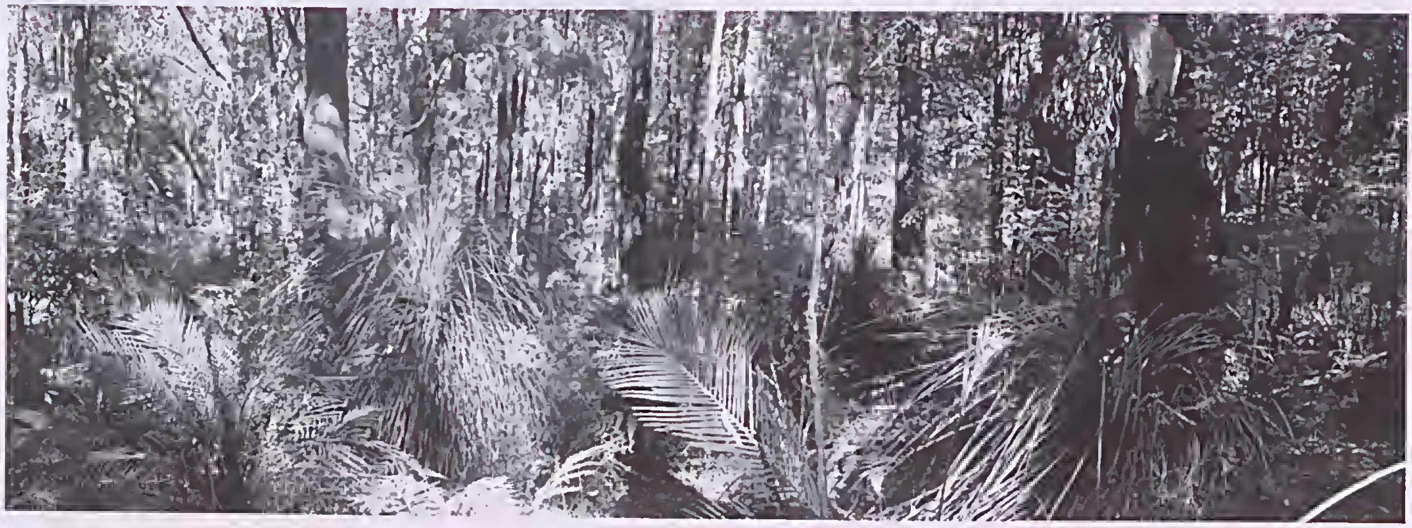


Fig. 11. Sydney Red Gum Forest with *Xanthorrhoea arborea* as a conspicuous element amongst thick scrub in the understorey

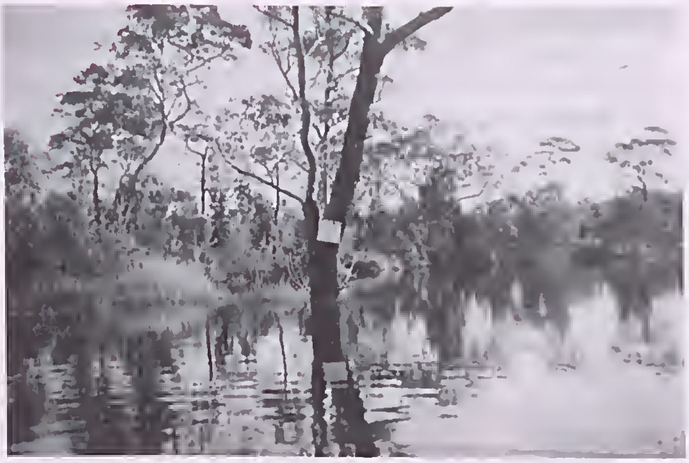


Fig. 12. Wetlands were a significant feature of the vegetation on the Umina-Woy Woy sandplain. This is Kahibah Swamp (part of Portion 98) in 1956. (Reproduced with permission from Gosford City Council).

Sedgeland/Herbland: *Cladium procerum – Bolboschoenus fluviatilis – Typha orientalis – Baumea articulata – Persicaria strigosa*

The Everglades Lagoon supports a more mixed type of wetland vegetation although it is heavily modified (Figure 13). The sedges comprise *Cladium procerum, Bolboschoenus fluviatilis, Typha orientalis* Cumbungi, *Baumea articulata* with herbs of *Persicaria strigosa.* Drainage works have changed the water levels at the lagoon leaving the large root systems of *Melaleuca quinquenervia* trees exposed. This wetland is now invaded by the exotic *Alternanthera philoxeroides* Alligator Weed.

Related mapping units: MU 40 Swamp Oak Rushland Forest of House (2003) and Freshwater Typha Wetland E46a of Bell 2004)

Riparian Forest: *Melaleuca quinquenervia – Eucalyptus robusta*

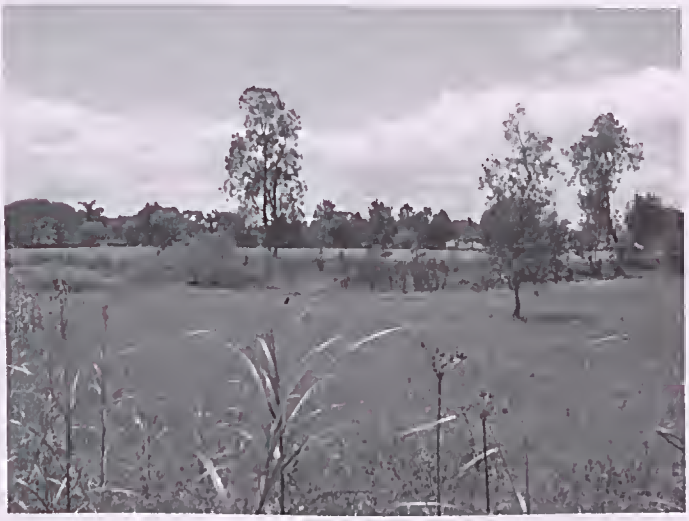


Figure 13 Sedgeland/Reedland/Herbland at the Everglades showing *Persicaria strigosa* with *Bolboschoenus fluviatilis* behind. Pockets of *Cladium procerum* and *Baumea articulata* are sporadic.

On the eastern edge of the Everglades Lagoon is a remnant forest of *Melaleuca quinquenervia* Broad-leaved Paperbark but around the fringes of this and other wetlands and along the drainage lines the species occurs with *Eucalyptus robusta* Swamp Mahogany. Smaller understorey trees are *Omalanthus populneus, Ficus coronata* and *Glochidion ferdinandi.* The understorey vegetation comprises *Carex appressa* and *Carex fasicularis.*

Riparian Forest with an understorey of *Baumea articulata* was once present in Etymalong Swamp but now only occurs as a narrow fringe beside residential properties.

Related mapping units: MU 33 Coastal Sand Apple Blackbutt Forest and MU 40 Swamp Oak Rushland Forest (House 2003) and Coastal Sand Swamp Forest of Bell (2004).

Riparian Palm Forest: *Eucalyptus robusta – Livistona australis – Casuarina glauca*

Along the lower reaches of Etymalong Creek a palm dominated riparian forest is found. This is the Coastal Sand Swamp Forest variant of Bell (2004). The forest type occurs at three sites on the Umina Woy Woy sandplain but originally may have occurred along drainage lines in some areas of the Pearl Beach sandplain. The Palm Forest on the alluvial fan behind Burdett Place Umina Beach (Figure 14) is included with this description.

Structure: Palm forest with a fern, sedge and reed understorey.

Habitat: Holocene sands (Woy Woy SLU) and subject to inundation. Ponds and soaks obvious. The vegetation community behind Burdett Place Umina was burnt out in the 2007 wildfire and has recovered.

Floristic Composition: The canopy is dominated by *Eucalyptus robusta* (Swamp Mahogany), *Livistona australis* (Cabbage Tree Palm) and *Casuarina glauca* (Swamp Oak) and occasionally *Angophora floribunda* (Rough-barked Apple). Sub-dominant trees include *Glochidion ferdinandi* (Cheese Tree), *Pittosporum undulatum* (Pittosporum), *Ficus coronata* (Sandpaper Fig) and *Alphitonia excelsa* (Red Ash). Dense pockets of small Cabbage Tree Palms and Sandpaper Fig trees make up part of the ground layer. The fern and sedge ground layer includes *Hypolepis muelleri* (Harsh Ground Fern), *Calochlaena dubia* (Common Ground Fern), *Blechnum indicum* (Swamp Water Fern) and *Cyclosorus interruptus*, whilst the sedges and reeds comprise *Cladium procerum, Schoenus imberbis, Gahnia clarkei* and *Phragmites australis* the Common Reed. Upslope of soaks the ground layer is mainly *Viola hederacea* (Native Violet), *Commelina*

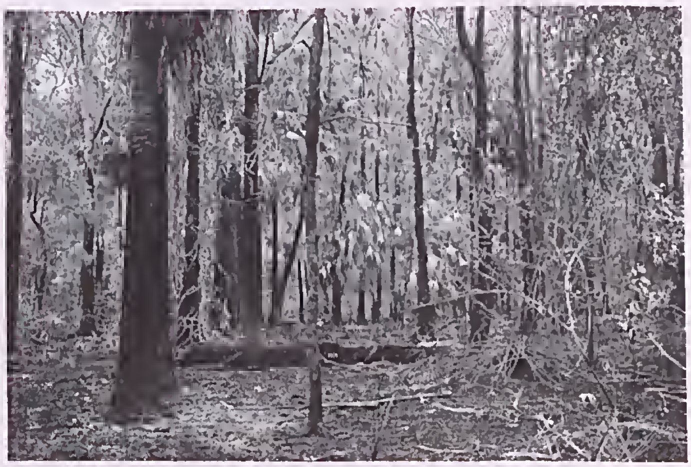


Figure 14 Burnt palms, *Livistona australis* at the rear of Burdett Place, Umina (rear of Old Etymalong Swamp).

cyanea, Oplismenus aemulus (Basket Grass) and *Entolasia marginata*. Regenerating plants of *Astrotricha floccosa* and *Alphitonia excelsa* are common behind Burdett Place.

Related mapping units: MU 37 Swamp Mahogany-Paperbark Swamp Forest of House (2003) and MU 37eii Coastal Sand Swamp Forest-Cabbage Tree variant of Bell (2004).

No description for the Coast Banksia shrubland along the frontal dunes is provided. Whilst the canopy is still intact, most of the area is either weedy or has been replaced by plantings with some areas undergoing bush regeneration. This community extended along Umina and Ocean Beaches, Pearl Beach and Patonga Beach, although at Patonga the shrubland tended to be mixed with UCSW. Historical photos show UCSW, along with species such as *Casuarina glauca* Swamp Oak, extended along the foreshore of Woy Woy Channel.

There are still large remnant trees of *Ficus rubiginosa* along the public foreshore of the Woy Woy Channel and Brisbane Water, suggesting pockets of littoral rainforest may once have been present but as no evidence of associated vegetation remains, no description can be provided.

Appendix 2

Plant species recorded from sandplain remnants at Umina and Pearl Beach showing Vegetation communities (mapunits), together with occurrence in area burnt in 1992 wildfire at Pearl Beach in 1988 (pre-fire) and 2004 (post–fire)

Coastal Holocene Dunes

1) Tall Shrubland: *Banksia integrifolia – Leptospermum laevigatum*

2) Umina Coastal Sandplain Woodland (UCSW)

Woodland: *Eucalyptus botryoides – Angophora floribunda*

3) Sydney Red Gum Complex (SRC)

Open Forest: *Angophora costata – Corymbia gummifera – Syncarpia glomulifera – Allocasuarina torulosa –Eucalyptus piperita – Eucalyptus resinifera*

Coastal Freshwater Swamps

4) Tall Sedgeland: *Lepironia articulata*

5) Rushland/Reedland: *Typha orientalis – Baumea articulata*

6) Sedgeland /Herbland: *Cladium procerum – Bolboschoenus fluviatilis – Typha orientalis – Baumea articulata – Persicaria strigosa*

7) Riparian Forest: *Melaleuca quinquenervia – Eucalyptus robusta*

8) Riparian Palm Forest *Eucalyptus robusta – Livistona australis – Casuarina glauca*

Species	**Family**	**Map unit**	**Pearl Beach Prefire (1988) - Postfire (2004**
Abrophyllum ornans	Escalloniaceae	2	
Acacia elata	Fabaceae	6	
Acacia floribunda	Fabaceae	2, 3	
Acacia irrorata subsp. *irrorata*	Fabaceae	5	
Acacia longifolia subsp. *longifolia*	Fabaceae	1, 2, 3, 7	88,04
Acacia oxycedrus	Fabaceae	2, 3	88
Acacia prominens	Fabaceae	5	
Acacia suaveolens	Fabaceae	2, 3	88,04
Acacia terminalis	Fabaceae	2, 3	88
Acacia ulicifolia	Fabaceae	2, 3	88,04
Acmena smithii	Myrtaceae	1,2, 3	88
Acronychia oblongifolia	Rutaceae	2	
Adiantum aethiopicum	Adiantaceae	2, 3, 5	88,04
Adiantum hispidulum	Adiantaceae	2	
Allocasuarina littoralis	Casuarinaceae	2	
Allocasuarina torulosa	Casuarinaceae	3, 5	88,04
Alocasia brisbanensis	Araceae	5	
Alphitonia excelsa	Rhamnaceae	1, 2.8	
Amperea xiphoclada	Euphorbiaceae	3	88
Angophora costata	Myrtaceae	2, 3	88,04
Angophora floribunda	Myrtaceae	2, 3, 7,8	88,04
Anisopogon avenaceus	Poaceae	3	88,04
Astroloma humifusum	Ericaceae	3	88,04
Astrotricha floccosa	Araliaceae	3	
Azolla filiculoides	Azollaceae	6	
Baloskion tetraphyllum subsp. *meiostachyum*	Restionaceae	2, 3	88,04
Banksia ericifolia	Proteaceae	5	
Banksia integrifolia	Proteaceae	2, 3	
Banksia serrata	Proteaceae	2, 3	88,04
Bauera rubioides	Baueraceae	3	88
Baumea articulata	Cyperaceae	5, 6	
Baumea teretifolia	Cyperaceae	5	
Billardiera scandens	Pittosporaceae	2, 3	88,04
Blechnum camfieldii	Blechnaceae	3	88,04
Blechnum cartilagineum	Blechnaceae	2, 3	88,04
Blechnum indicum	Blechnaceae	5,8	
Blechnum wattsii	Blechnaceae	3	88
Bolboschoenus fluviatilis	Cyperaceae	5, 6.7	
Bossiaea ensata	Fabaceae	3	88
Bossiaea heterophylla	Fabaceae	3	88,04
Breynia oblongifolia	Euphorbiaceae	2, 3	88,04
Bursaria spinosa	Pittosporaceae	3	88,04
Caesia parviflora	Anthericaceae	5	
Caladenia capillata	Orchidaceae	3	88
Callicoma serratifolia	Cunoniaceae	2	
Callistemon citrinus	Myrtaceae	3	88,04
Callistemon linearifolius	Myrtaceae	3	88
Calochilus gracillimus	Orchidaceae	3	88
Calochlaena dubia	Dicksoniaceae	3, 5,8	88
Carex appressa	Cyperaceae	5, 6, 7	
Carex fascicularis	Cyperaceae	7	
Carpobrotus glaucescens	Aizoaceae	1	
Cassytha pubescens	Lauraceae	2, 3, 5	88,04
Cassytha spp.	Lauraceae	3	
Casuarina glauca	Casuarinaceae	2, 5, 7	
Cayratia clematidea	Vitaceae	2, 5	
Centella asiatica	Apiaceae	5	
Ceratopetalum apetalum	Cunoniaceae	2, 3, 4, 5	88,04
Ceratopetalum gummiferum	Cunoniaceae	3	88,04
Chiloglottis spp.	Orchidaceae	3	
Christella dentata	Thelypteridaceae	3	88
Cissus antarctica	Vitaceae	2	
Cissus hypoglauca	Vitaceae	1, 2, 3, 5	88,04
Cladium procerum	Cyperaceae	5, 6, 7	
Clematis glycinoides	Ranunculaceae	2, 3	88,04
Clerodendrum tomentosum	Verbenaceae	2, 3	88,04
Comesperma ericinum	Polygalaceae	2	
Commelina cyanea	Commelinaceae	1, 2, 3, 5	88,04
Correa reflexa var. reflexa	Rutaceae	3	88
Corymbia gummifera	Myrtaceae	2, 3	88,04
Cotula australis	Asteraceae	5	
Crinum pedunculatum	Amaryllidaceae	7	
Crowea exalata subsp. *exalata*	Rutaceae	3	88
Cyathea australis	Cyatheaceae	3	88,04
Cyathea leichhardtiana	Cyatheaceae	3	88
Cyathochaeta diandra	Cyperaceae	3	
Cymbidium suave	Orchidaceae	3	88
Cymbopogon refractus	Poaceae	3	88
Cynodon dactylon	Poaceae	3, 6	88
Cyperus difformis	Cyperaceae	5	
Cyperus exaltatus	Cyperaceae	5	
Cyperus polystachyos	Cyperaceae	5	
Dampiera stricta	Goodeniaceae	3	88,04
Desmodium brachypodum	Fabaceae	3, 5	88
Dianella caerulea var. *caerulea*	Phormiaceae	2	88,04
Dianella caerulea var. *producta*	Phormiaceae	3	
Dianella congesta	Phormiaceae	1, 2	
Dianella longifolia	Phormiaceae	2	
Dichelachne crinita	Poaceae	5	
Dichondra repens	Convolvulaceae	3	88
Digitaria breviglumis	Poaceae	2	
Dillwynia floribunda	Fabaceae	3	88,04
Dioscorea transversa	Dioscoreaceae	3	88
Dipodium punctatum	Orchidaceae	3	88
Dodonaea triquetra	Sapindaceae	2, 3, 5	88,04
Doodia aspera	Blechnaceae	2	
Elaeocarpus reticulatus	Elaeocarpaceae	2, 3	88,04
Eleocharis sphacelata	Cyperaceae	3, 5	88
Empodisma minus	Restionaceae	3	
Entolasia marginata	Poaceae	3, 5	
Entolasia stricta	Poaceae	2, 3	88
Epacris longiflora	Ericaceae	3	88
Epacris microphylla	Ericaceae	3	88
Eriostemon australasius	Rutaceae	2	

Species	**Family**	**Map unit**	**Pearl Beach Prefire (1988) Postfire (2004**
Eucalyptus botryoides	Myrtaceae	2, 7	
Eucalyptus paniculata	Myrtaceae	2, 3, 7	88,04
Eucalyptus piperita	Myrtaceae	3	88,04
Eucalyptus punctata	Myrtaceae	3	88,04
Eucalyptus resinifera	Myrtaceae	3	
Eucalyptus robusta	Myrtaceae	2, 5, 6.8	
Eucalyptus umbra	Myrtaceae	3	88,04
Eupomatia laurina	Eupomatiaceae	2	
Euroschinus falcata var *falcata*	Anacardiaceae	2	
Eustrephus latifolius	Luzuriagaceae	1, 2, 3, 5	88,04
Exocarpos cupressiformis	Santalaceae	2	
Ficus coronata	Moraceae	6, 7	
Ficus rubiginosa	Moraceae	2, 7	
Gahnia clarkei	Cyperaceae	3, 5	88,04
Geitonoplesium cymosum	Luzuriagaceae	1, 3	88
Geranium homeanum	Geraniaceae	5	
Gleichenia dicarpa	Gleicheniaceae	3, 5	88,04
Glochidion ferdinandi var. *ferdinandi*	Euphorbiaceae	2, 3, 5, 6, 7	88,04
Glycine clandestina	Fabaceae	2, 3	88,04
Gompholobium latifolium	Fabaceae	2, 3	88
Gonocarpus tetragynus	Haloragaceae	2	
Gonocarpus teucrioides	Haloragaceae	3	88
Grevillea linearifolia	Proteaceae	5	
Guioa semiglauca	Sapindaceae	2	
Gymnostachys anceps	Araceae	2, 3	88,04
Hardenbergia violacea	Fabaceae	2, 3	88
Hemarthria uncinata	Poaceae	3	
Hibbertia aspera	Dilleniaceae	3	88
Hibbertia dentata	Dilleniaceae	3,8	88,04
Hibbertia diffusa	Dilleniaceae	2, 3	88
Hibbertia empetrifolia subsp. *empetrifolia*	Dilleniaceae	3	88
Hibbertia fasciculata	Dilleniaceae	2	
Hibbertia obtusifolia	Dilleniaceae	2	
Hibbertia scandens	Dilleniaceae	1, 2, 3	88
Histiopteris incisa	Dennstaedtiaceae	4	88,04
Homalanthus populifolius	Euphorbiaceae	3, 5, 6,7	88
Hovea lanceolata	Fabaceae	2	
Hybanthus monopetalus	Violaceae	2, 3	88,04
Hydrocotyle laxiflora	Apiaceae	2	
Hydrocotyle peduncularis	Apiaceae	2, 5	
Hydrocotyle tripartita	Apiaceae	5	
Hydrocotyle verticillata	Apiaceae	5	
Hypolepis muelleri	Dennstaedtiaceae	3, 5	88,04
Imperata cylindrica var. *major*	Poaceae	1, 2, 3,8	
Indigofera australis	Fabaceae	3	88
Isachne globosa	Poaceae	5	
Isolepis cernua	Cyperaceae	5, 6	
Isolepis nodosa	Cyperaceae	1, 2	88
Juncus planifolius	Juncaceae	3, 5	88
Juncus prismatocarpus	Juncaceae	5	
Juncus usitatus	Juncaceae	6	
Kennedia rubicunda	Fabaceae	2, 3	88,04
Lasiopetalum ferrugineum var. *ferrugineum*	Sterculiaceae	3	88
Lastreopsis microsora subsp. *microsora*	Dryopteridaceae	3	88
Lepidosperma elatius	Cyperaceae	3	
Lepidosperma laterale	Cyperaceae	3	88,04
Lepidosperma longitudinale	Cyperaceae	2	
Lepironia articulata	Cyperaceae	4	
Leptomeria acida	Santalaceae	3	88,04
Leptospermum laevigatum	Myrtaceae	2, 3, 5	
Leptospermum polygalifolium	Myrtaceae	2, 3,5,7	88,04
Leptospermum trinervium	Myrtaceae	2	
Livistona australis	Arecaceae	3, 5, 7.8	88,04
Lobelia anceps	Lobeliaceae	5	
Lobelia dentata	Lobeliaceae	2	
Logania albiflora	Loganiaceae	3	88,04
Lomandra filiformis subsp. *coriacea*	Lomandraceae	2	
Lomandra longifolia	Lomandraceae	1, 2, 3	88,04
Lomandra multiflora subsp. *multiflora*	Lomandraceae	3	88,04
Lomandra obliqua	Lomandraceae	3	88,04
Ludwigia peploides subsp. *montevidensis*	Onagraceae	6	
Macrozamia communis	Zamiaceae	2, 3, 5, 6	88,04
Maytenus silvestris	Celastraceae	3	
Melaleuca linariifolia	Myrtaceae	5,8	
Melaleuca quinquenervia	Myrtaceae	2, 5, 6	
Melia azedarach	Meliaceae	7	
Microlaena stipoides	Poaceae	1, 3, 5	88
Mitrasacme polymorpha	Loganiaceae	2, 3	88
Monotoca elliptica	Ericaceae	2, 3	88,04
Morinda jasminoides	Rubiaceae	2, 5	
Myoporum acuminatum	Myoporaceae	5	
Myrsine variabilis	Myrsinaceae	2, 3	88,04
Notelaea longifolia	Oleaceae	3	88
Opercularia aspera	Rubiaceae	2	
Opercularia hispida	Rubiaceae	2	
Oplismenus aemulus	Poaceae	2	
Oxalis perennans	Oxalidaceae	1	
Pandorea pandorana	Bignoniaceae	1,2, 3	88,04
Panicum effusum	Poaceae	3	
Parsonsia straminea	Apocynaceae	2, 3, 5, 7	88
Paspalum distichum	Poaceae	6	
Patersonia sericea	Iridaceae	3	88,04
Pellaea falcata	Adiantaceae	1, 2, 7	
Persicaria decipiens	Polygonaceae	5, 6	
Persicaria strigosa	Polygonaceae	3, 5, 6, 7	88,04
Persoonia lanceolata	Proteaceae	3	
Persoonia levis	Proteaceae	3	88
Persoonia linearis	Proteaceae	1, 3	88
Persoonia pinifolia	Proteaceae	3	88,04
Philydrum lanuginosum	Philydraceae	3, 5	88

Species	Family	Map unit	Pearl Beach Prefire (1988) - Postfire (2004
Phragmites australis	Poaceae	4, 6	
Phyllanthus hirtellus	Euphorbiaceae	2, 3	88,04
Pittosporum multiflorum	Pittosporaceae	2, 3	88,04
Pittosporum revolutum	Pittosporaceae	1, 2	
Pittosporum undulatum	Pittosporaceae	1, 2, 3, 5 ,7	88,04
Platylobium formosum subsp. *formosum*	Fabaceae	2, 3	88,04
Platysace lanceolata	Apiaceae	2, 3	
Platysace linearifolia	Apiaceae	3	88,04
Poa affinis	Poaceae	5	
Podocarpus spinulosus	Podocarpaceae	3	88,04
Pomaderris ferruginea	Rhamnaceae	3	88,04
Pomaderris intermedia	Rhamnaceae	2	88
Pomax umbellata	Rubiaceae	2, 3	88,04
Pratia purpurascens	Lobeliaceae	3	88
Prostanthera linearis	Lamiaceae	3	88,04
Pseuderanthemum variabile	Acanthaceae	2, 3, 5	88,04
Pseudognaphalium luteo-album	Asteraceae	5	
Psychotria loniceroides	Rubiaceae	3	88
Pteridium esculentum	Dennstaedtiaceae	1, 2, 3	88,04
Pterostylis nutans	Orchidaceae	3	88
Pultenaea daphnoides	Fabaceae	3	88,04
Pultenaea flexilis	Fabaceae	3, 5	88,04
Pultenaea linophylla	Fabaceae	5	
Ranunculus inundatus	Ranunculaceae	5	
Rhodamnia rubescens	Myrtaceae	2	
Rhodomyrtus psidioides	Myrtaceae	2	
Ricinocarpos pinifolius	Euphorbiaceae	2, 3	88,04
Rubus moluccanus var. *trilobus*	Rosaceae	2, 5	
Sarcopetalum harveyanum	Menispermaceae	3	88
Scaevola ramosissima	Goodeniaceae	3	88
Schelhammera undulata	Uvulariaceae	3	88,04
Schizaea bifida	Schizaeaceae	3	88,04
Schizaea dichotoma	Schizaeaceae	3	
Schizomeria ovata	Cunoniaceae	2, 5	88,04
Schoenus apogon	Cyperaceae	6	
Schoenus brevifolius	Cyperaceae	2, 3	88,04
Selaginella uliginosa	Selaginellaceae	2, 3	88,04
Senecio diaschides	Asteraceae	2	
Senecio lautus subsp. *lanceolatus*	Asteraceae	2	
Sigesbeckia orientalis subsp. *orientalis*	Asteraceae	5	
Smilax australis	Smilacaceae	3	88
Smilax glyciphylla	Smilacaceae	1, 2, 3	88,04
Solanum elegans	Solanaceae	3, 5	
Solanum mauritianum	Solanaceae	3	
Stephania japonica var. *discolor*	Menispermaceae	1, 2, 5	
Sticherus flabellatus var. *flabellatus*	Gleicheniaceae	3	88,04
Stylidium graminifolium	Stylidiaceae	3	88
Syncarpia glomulifera	Myrtaceae	3	88,04
Synoum glandulosum subsp. *glandulosum*	Meliaceae	2, 3	88,04
Syzygium oleosum	Myrtaceae	3, 7	88
Tetragonia tetragonioides	Aizoaceae	1	
Tetratheca ericifolia	Tremandraceae	2	
Themeda australis	Poaceae	2, 3	88,04
Todea barbara	Osmundaceae	3	88
Trema tomentosa var. *viridis*	Ulmaceae	4, 6	
Triglochin procerum	Juncaginaceae	6, 7	
Triglochin striatum	Juncaginaceae	8	
Trochocarpa laurina	Ericaceae	1, 2, 3	
Typha orientalis	Typhaceae	5, 6	
Villarsia exaltata	Menyanthaceae	5	
Viminaria juncea	Fabaceae	3	88,04
Viola caleyana	Violaceae	6	
Viola hederacea	Violaceae	3, 6	88,04
Wahlenbergia gracilis	Campanulaceae	3, 6	88
Wilkiea huegeliana	Monimiaceae	1, 2	88
Woollsia pungens	Ericaceae	3	88,04
Xanthorrhoea arborea	Xanthorrhoeaceae	3	88,04
Xanthorrhoea media	Xanthorrhoeaceae	3	88,04
Xanthosia pilosa	Apiaceae	3	88,04
Xylomelum pyriforme	Proteaceae	3	88,04
INTRODUCED SPECIES			
*_Ageratina adenophora_	Asteraceae		88
*_Aira caryophyllea_	Poaceae		88
*_Andropogon virginicus_	Poaceae		88,04
*_Asparagus officinalis_	Asparagaceae		
Brachychiton acerifolius	Sterculiaceae		
*_Cinnamomum camphora_	Lauraceae		88,04
*_Ehrharta erecta_	Poaceae		
*_Erechtites valerianifolia_	Asteraceae		
*_Geranium molle_ subsp. _molle_	Geraniaceae		
*_Hydrocotyle bonariensis_	Apiaceae		
*_Hypochaeris radicata_	Asteraceae		88,04
*_Lantana camara_	Verbenaceae		88,04
*_Ligustrum sinense_	Oleaceae		
*_Lonicera japonica_	Caprifoliaceae		88,04
*_Melastoma affine_	Melastomaceae		
*_Nephrolepis cordifolia_	Davalliaceae		88,04
*_Ochna serrulata_	Ochnaceae		88,04
*_Panicum effusum_	Poaceae		88
*_Paspalum urvillei_	Poaceae		88
*_Passiflora edulis_	Passifloraceae		88,04
*_Poa annua_	Poaceae		88
*_Senna pendula_ var. _glabrata_	Fabaceae (Caesalpinioideae)		88,04
*_Setaria sp._	Poaceae		88
*_Sida rhombifolia_	Malvaceae		88
*_Tradescantia fluminensis_	Commelinaceae		88

Biomass and floristic patterns in the ground layer vegetation of box-gum grassy eucalypt woodland in Goorooyarroo and Mulligans Flat Nature Reserves, Australian Capital Territory

S. McIntyre, J. Stol, J. Harvey, A. O. Nicholls, M. Campbell, A. Reid, A. D. Manning and D. Lindenmayer

Corresponding author: Sue McIntyre, CSIRO Sustainable Ecosystems, PO Box 284, Canberra ACT 2601 AUSTRALIA
Email: Sue.Mcintyre@csiro.au.

Abstract: We establish a methodology and present baseline data for a long-term grassy woodland restoration study that commenced in 2007 in two nature reserves (Mulligans Flat, Goorooyarroo (35° 9–13' S; 149° 9–12' E)) totalling 1386 ha on the northern boundary of Canberra, in the Australian Capital Territory in south eastern Australia. The experimental infrastructure comprises 96 × 1 ha sites established in *Eucalyptus blakelyi* / *Eucalyptus melliodora* dominated woodland. These are being subjected to varying kangaroo grazing pressure and augmentation with logs, while burning treatments are planned. One reserve (Mulligans Flat) has been fenced for feral predator control and contains half the sites, forming a companion experiment to Goorooyarroo. Our baseline floristic study comprised estimates, at the site level, of ground layer biomass, species biomass, ground cover types and soil (0–10 cm) properties. From these data we conclude that the groundlayer vegetation is dominated by *Joycea pallida*, *Austrodanthonia* spp., *Themeda australis* and *Aristida ramosa*. These grasses varied in abundance according to differences in soil pH, phosphorus and to a lesser extent nitrates. Forb frequencies were highly sensitive to nitrate levels with annual exotic forbs dominating at high nitrate sites. More generally, soil nutrient levels and exotic species in some sites indicated areas of previous pasture improvement activities. Biomass estimates indicated extremely high grazing pressure, sufficient to negatively affect the habitat quality for ground-dependent fauna and some soil processes. These data will provide an important basis for examining rates of ecosystem recovery under different restoration strategies.

Key words: macropod grazing, woodland restoration, grassland, BOTANAL, grassy woodland, ecosystem restoration, phosphorus tolerance

***Cunninghamia* (2010) 11(3): 319–357**

Introduction

Temperate grassy woodlands are an ecological community of major concern in conservation management owing to the pervasive and often severe effects of pastoralism on their floristic composition and ecological functioning. Extensive areas in good condition do not exist, and so the establishment of significant conservation reserves invariably involves the need for restoration and active management. Such a task is currently being undertaken in the Australian Capital Territory (ACT) in south eastern Australia in two adjacent reserves: Mulligans Flat Nature Reserve: 683 ha established in 1994 and Goorooyarroo Nature Reserve: 702 ha established in 2006 (Lyn Jones, ACT Planning and Land Authority pers. comm.).

The management changes since the establishment of these reserves have been the removal of livestock, cessation of pasture improvement and protection from tree clearing and firewood removal. Other active management includes the control of exotic weeds (primarily serrated tussock *[1]*Nasella tricotoma* and sweet briar **Rosa rubiginosa*). However, the effects of previous pastoralism on the ecosystems are significant, and it cannot be assumed that protection status alone will allow the ecosystems to spontaneously recover their complete diversity and function. Some elements may recover over time (e.g. mature tree densities, fallen timber, soil condition) and others may need more active management to either address inappropriate processes operating, or to reverse transformative actions that have led to alternative stable states. An example of an inappropriate process is the

---

*[1]. Exotic species are denoted with an asterisk throughout the text and tables.

© 2010 Botanic Gardens Trust

high grazing pressure resulting from large populations of macropods that have developed in the absence of predators, and in response to changes in pasture and the provision of dams (Caughley et al. 1980; Viggers & Hearn 2005). An example of a transformative action is conversion to exotic plant dominance due to grazing, the use of fertilizers and the introduction of exotic species (Prober et al. 2002b; McIntyre & Lavorel 2007).

In 2004, in recognition of the importance of the need to improve management of grassy woodlands, a partnership was formed between the Australian Capital Territory Government and The Australian National University to experimentally impose active management to improve the woodlands for biodiversity, with an emphasis on the fauna and woody vegetation (Manning et al. in prep.). CSIRO Sustainable Ecosystems has joined the partnership to provide data on understory vegetation condition. The first stage of these research partnerships has been to collect baseline data on biodiversity and resource condition and to establish experimental treatments. It is envisaged that while some changes will be readily observable, it will take decades to detect some treatment effects, and that the project will necessarily be medium- to long-term. It is therefore important to establish an accessible, well-documented baseline data set at the beginning of the project.

Fig. 1a. General view of Goorooyarroo Nature Reserve showing grassy woodland on rolling hills (Photo S. McIntyre).

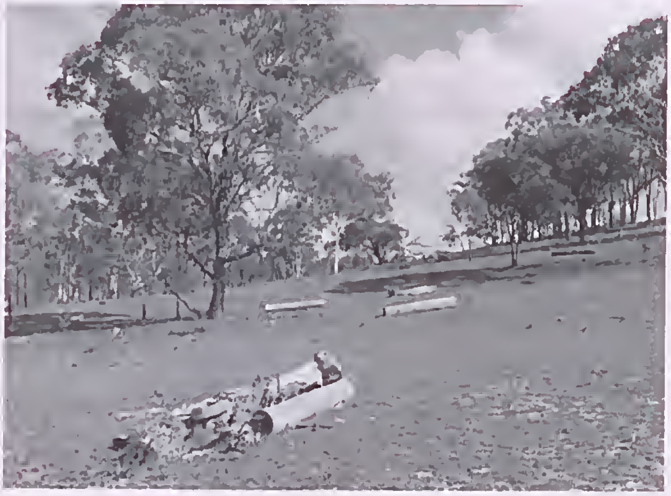


Fig. 1b. Clumped and scattered timber addition (40 tonne.ha^{-1}) on *Themeda* lawn in Mulligans Flat (Photo S. McIntyre).

The objectives of this paper are twofold. First, we provide a description of the groundlayer vegetation and its floristic patterns. There is little published information on the vegetation in this area beyond a general description of Mulligans Flat and a species list (Lepschi 1993). In our analysis, we provide an overview of the composition and condition of woody and herbaceous vegetation less than 0.5 m in height in both Mulligans Flat and Goorooyarroo reserves. Through multivariate analysis, we have also sought to identify major variation in the vegetation and identify soil and other site factors that might be associated with this variation. Our second objective is to provide a permanent record of the baseline data to underpin long-term studies of floristic change and ecological condition. An additional use of these data will be to inform the interpretation of the faunal data sets being collected, and this has influenced the vegetation survey protocol.

Table 1. Rainfall at the Canberra airport prior to and during the survey in 2007, and long-term averages for the same months. Note district rainfall varies greatly and estimated annual rainfall for the reserves is 650 mm (Jenkins 2000)

Month	Total rainfall 2007 (mm)	Long-term average for month (mm)
January	10	59
February	95	55
March	37	50
April	28	46
May	42	44
June	93	41
July	19	41
August	12	47
September	15	52
October	23	63
November	95	64
December	101	54
Annual	**568**	**615**

Reserve features and overall experimental design

The two reserves total 1,386 ha and are joined along a boundary of 300–400 m and located within 35° 9–13' S; 149° 9–12' E. Elevation ranges from 650 – 700 m and mean annual rainfall is about 650 mm (Table 1; Jenkins 2000). The soils in the reserves are derived from Silurian volcanics that form the ridges and Silurian sedimentary rocks. Four intergrading soil landscapes have been identified in the area:

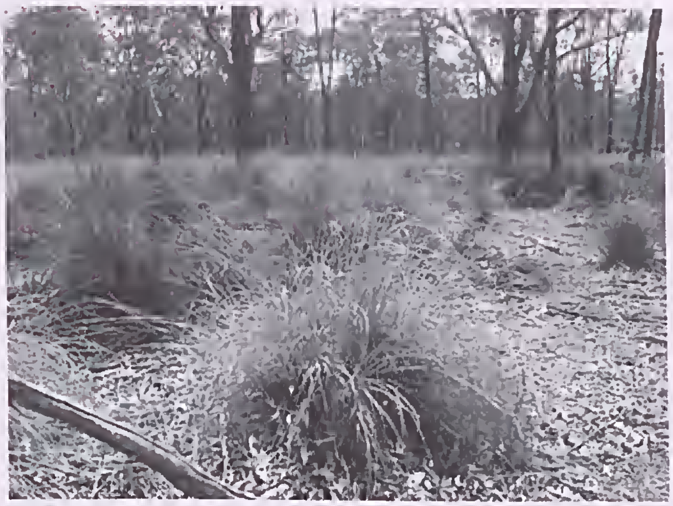


Fig. 1c. *Joycea pallida* dominates on acid soils of low fertility and forms large tussocks that are largely avoided by grazers (Photo J. Stol).

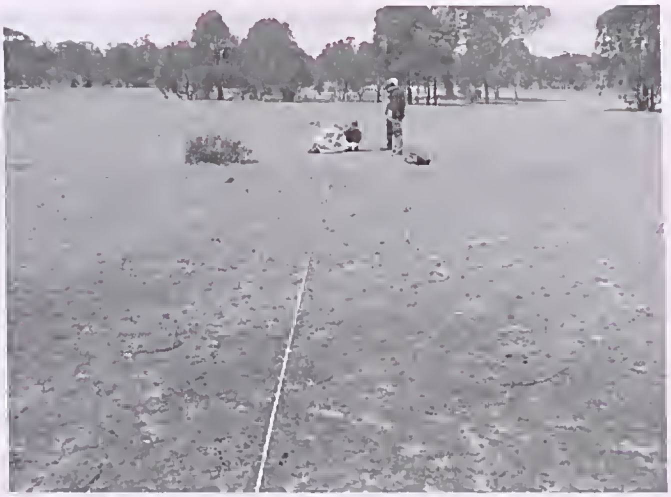


Fig. 1e. Heavy macropod grazing was pervasive. This grazing lawn is dominated by *Austrodanthonia* and had a biomass of 280 kg.ha^{-1} (Photo S. McIntyre).

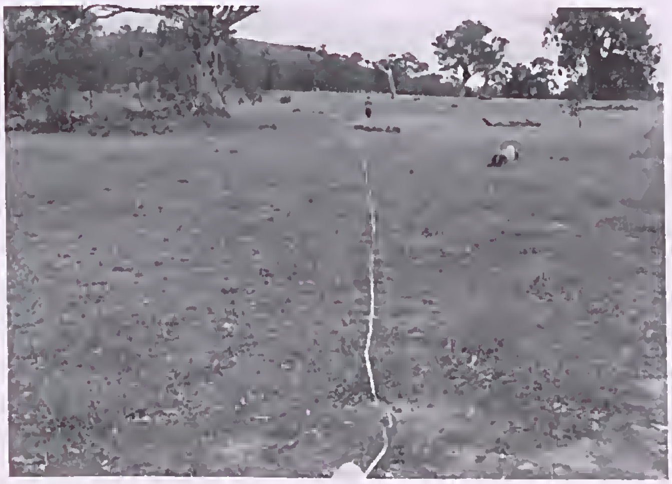


Fig. 1d. Group 1 site with history of previous pasture development - elevated phosphorus and nitrates supporting **Phalaris* , **Trifolium* and *Austrodanthonia* as dominants (Photo J. Stol).

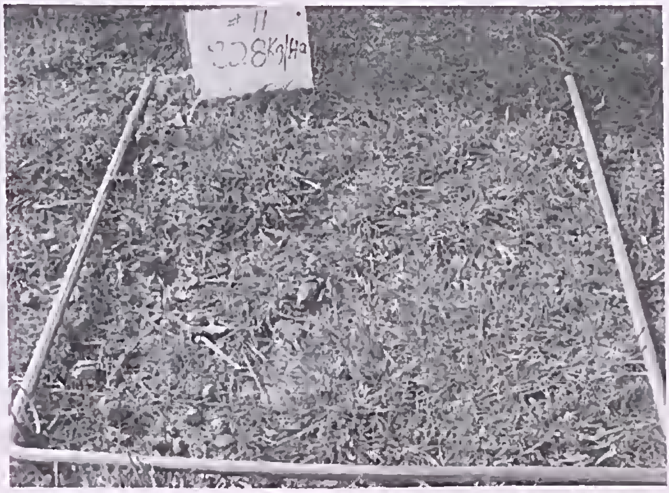


Fig. 1f. *Themeda* dominance was associated with high grazing pressure on the less acid soils with low nitrates and moderate phosphorus levels. This quadrat was 828 kg.ha^{-1}, well above the average of 570 kg.ha^{-1} (Photo S. McIntyre).

Campbell, Burra, Williamsdale and Franklin (Jenkins 2000). These vary mainly in their topography, ranging from rolling hills (Campbell)(Fig. 1a), low hills (Burra), to undulating plains and flats (Franklin, Williamsdale). Yellow Podzolic soils are associated with all these landscapes, with various occurrences of Red Podzolics, Red and Yellow Earths, Solodic, Solonized Solonetz and Alluvial soils (Sleeman & Walker 1979; Jenkins 2000).

Three broad vegetation types were recognized by Lepschi (1993) in his description of Mulligans Flat: 1) open forest on the shallower soils of the ridges and slopes dominated by *Eucalyptus macrorhyncha*, *Eucalyptus rossii* and *Eucalyptus mannifera*; 2) woodlands on the deeper soils of the lower slopes and flats (*Eucalyptus blakelyi* and *Eucalyptus melliodora*) and 3) patches of grassland dominated by *Panicum effusum*, *Themeda australis* and *Austrodanthonia* spp. The woodlands are a critically endangered ecological community under the *Environment Protection and Biodiversity Conservation Act 1999* (Box-Gum Grassy Woodlands and Derived Grasslands) and are the focus of the experiment. The primary criteria for location of the experimental sites was that the dominant tree species be *Eucalyptus blakelyi* and *Eucalyptus melliodora*. However, there are gradients between vegetation types (Lepschi 1993), particularly with *Eucalyptus macrorhyncha* and this species was well represented in sites in Mulligans Flat. In addition, the 'woodland' species (*Eucalyptus blakelyi* and *Eucalyptus melliodora*) are densely regenerating in places and are developing a forest structure. Given a history of clearing and subsequent regeneration, and in the absence of an endogenous disturbance regime, identifying and creating appropriate tree densities across the reserves will pose a challenge for managers.

The experimental infrastructure comprises 96 × 1 ha permanently marked sites, 48 sites in each reserve, across which a number of treatments are being imposed (or are planned):

- Kangaroo control though fencing and partial exclosure (two levels of grazing, uncontrolled or reduced).
- Fallen timber augmentation (none, 20 tonnes.ha^{-1} dispersed, 20 tonnes.ha^{-1} clumped, 40 tonnes.ha^{-1} both clumped and dispersed. Fig.1b).
- Fire (burned, not burned, regime yet to be determined).

These treatments are being imposed on four tree and shrub density classes that represent a range of existing densities in the reserves: 1) high tree – low shrub; 2) high tree – high shrub; 3) low tree – low shrub; 4) low tree – high shrub. The 48 sites in each reserve are being treated as two companion experiments. This is primarily due to the management of Mulligans Flat sites as a feral predator free site, with the establishment of a predator-proof fence around all the sites in this reserve. None of the sites in Goorooyarroo are fenced in this way.

Further details of the experiment and its implementation are being reported elsewhere (Manning *et al.* in prep) and are not germane to this paper as the treatments had either not yet been implemented (kangaroo control, fire, feral pest exclusion) or had only been implemented within weeks of vegetation sampling (fallen timber augmentation). Augmented fallen timber was in the form of eucalypt main stems (smaller branches and bark removed) salvaged from Canberra suburbs and placed across the sites with a logging forwarder (Fig.1b).

Methods for sampling ground layer vegetation

In this survey, ground layer vegetation comprised herbaceous species as well as individuals of woody plants that were less than 0.5 m high (regardless of potential height). Vegetation was sampled between 12th October and 27th November 2007. A field team of four people completed the floristic survey which took 25 days. All 96 sites were sampled. Thirty quadrats (0.5 × 0.5 m) were located systematically across each site (see Fig. 2). Measuring tapes were run out from the permanent posts to mark the spine of the site and the 20 m intervals, while the 15m intervals were paced out at right angles from the central tape (Fig. 2). There was some variation in the distance between the two permanent posts, so we used post B as the absolute reference point for the location of the quadrats. Quadrats falling on logs (whether pre-existing or part of the treatment addition) or live tree stems were not displaced around these features.

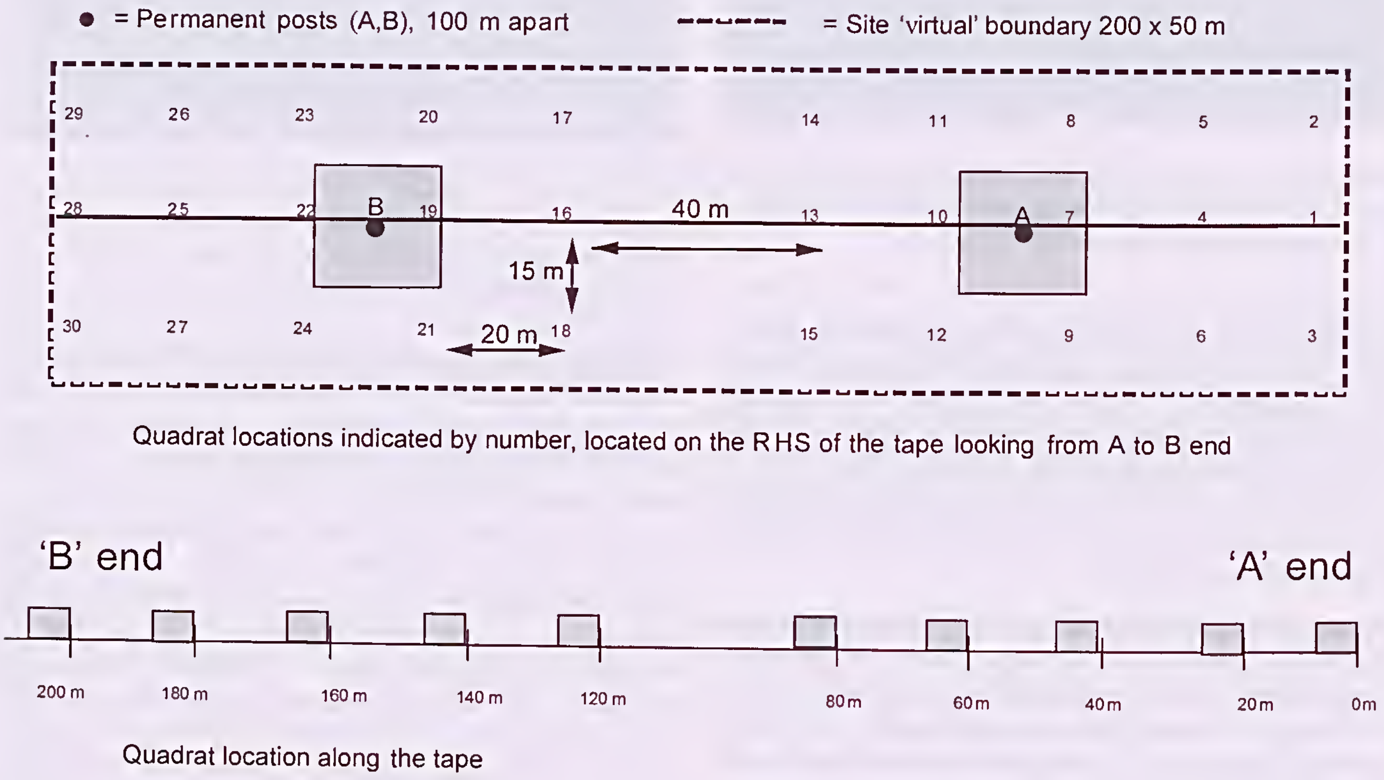

● = Permanent posts (A,B), 100 m apart
= Site 'virtual' boundary 200 x 50 m
29 26 23 20 17 14 11 8 5 2
28 25 22 B 19 16 40 m 13 10 A 7 4 1
15 m
30 27 24 21 20 m 18 15 12 9 6 3
Quadrat locations indicated by number, located on the RHS of the tape looking from A to B end
'B' end
'A' end
200 m 180 m 160 m 140 m 120 m 80m 60m 40m 20m 0m
Quadrat location along the tape

Fig 2. Plant sampling layout within the 96 x1 ha permanent sites showing location of permanent posts (A, B), boundary of site (referenced from posts), numbered location of the 30 quadrats sampled (non-permanent) and relative position of the quadrats along the three transect lines (non-permanent).

Ground cover characterization

We used point–based estimates of ground cover, one point in each of the four corners of the quadrats, giving a total of 120 points per site. At each point, we recorded the type of ground cover defined as follows:

Litter – included organic material that was unattached to a plant or the ground and included stems, leaves, bark, animal dung, sticks diameter <10 cm and shorter than 0.5m. If litter was present, we measured its depth to the nearest mm.

Cryptogams – included moss, lichen, liverwort, thick algal crusts.

Bare – included loose rock with longest side ≤20 cm, bare earth, earth with thin layer of algae.

Rock – any size, attached to the ground or loose rock, with longest side >20 cm.

Fallen logs – minimum diameter of 10 cm, minimum length of 0.5 m, smaller sizes are included in litter. A section of the log having a 10 cm diameter needed to be in the quadrat for it to qualify as a log.

Live plant basal area – the attachment area of the ground occupied by the stem or tiller bases of non-cryptogam plants, including the basal area of live tree stems.

Ground cover was thus characterized as % cover of litter, cryptogams, bare ground, rock, fallen logs and basal area. Average litter depth (where litter present) was also calculated.

Tree and shrub count

We recorded number and identification of eucalypts with a height of <0.5 m. Shrubs with a height of <0.5 m in the quadrats were recorded as part of the ground layer biomass data (see methods below). We also recorded identity and numbers of all non-eucalypt shrubs ≥0.5 m high and a DBH of ≤2cm, even if the same species was recorded in the ground layer data. Trees and shrubs were counted only if they were rooted in the quadrat.

Methods for ground layer biomass and composition

We used the BOTANAL method for estimating species abundance (t' Mannetje & Haydock 1963, Tothill et al. 1992) which requires species to be ranked in terms of biomass and the total biomass to be estimated.

Species rankings

Dominant species were ranked according to their contribution to dry weight of biomass (green and dead attached tissues) and the top six species recorded to enable assessment of contribution of abundant forbs to the sward. Winter growing annuals were included in the ranking even if dried off, as long as they were identifiable. Species were ranked according to the amount of foliage projected over the quadrat, regardless of where it was rooted.

Total biomass estimates

Total biomass (both green and dead attached tissues) was estimated for each quadrat. Estimates did not include any eucalypt, or shrub >0.5 m high of any species in the total biomass estimates. If there were any herbaceous plants that were higher than 0.5 m, they were included in the total biomass estimates. We included only higher plants and true ferns but not cryptogams (ie no lichen, moss, liverworts, pre-ferns).

Sixteen standards were established to train two members of the field team in biomass estimation, representing the range of structures and biomass available. Two adjacent closely matched 0.5 × 0.5 m quadrats were selected, one was photographed and cut, the other left and marked out as the visual standard. Live plants and dead attached litter were cut at ground level. Material was oven dried at 80°C to constant weight to provide correct dry weights. The team used these standards to establish their estimation skills, and used the photos for later reference.

Consistent bias by individual observers was addressed by using individual calibration regressions of estimates following the approach of Tothill et al. (1992). Halfway though the sampling, 20 quadrats were located across a range of biomass levels and the total biomass estimated by each operator. These were then cut, dried and weighed. This process was repeated on the completion of sampling. The 40 calibrated estimates were used in regressions to adjust the total biomass data. Straight line regressions were obtained with R^2 values of 0.93 and 0.97.

Species composition data

To calculate species composition from the estimate of total biomass and species rankings, the proportional contribution (PR) was calculated using the following geometric series:

$PR = (1-k)*k^{R-1}$

where R is the Rank order, and k is a parameter. We used a k = 0.3 (best match for empirical results, Scott 1986), which give % contributions of: Rank 1 = 70%, Rank 2 = 21%, Rank 3 = 6.3%, Rank 4 = 1.9%, Rank 5 = 0.6%, Rank 6 = 0.2%.

If a maximum of 3, 4, or 5 species were recorded in a quadrat, the above weightings were not changed, as the non-existent ranks (4, 5 and 6) totalled a maximum of 2.7%, and we regarded this amount of unaccounted-for biomass as acceptable. If there were two species only in a quadrat, the weighting used was 70%, 30%. Ties were used if two species had similar biomass, in which case, the next rank was not filled. For ties, the two or three relevant tied ranks were added together and divided evenly e.g. 2–3 tied was weighted 70, 13.65, 13.65, 1.9, 0.6, 0.2; 1–3 tied was 32.4, 32.4, 32.4, 1.9, 0.6, 0.2%.

For highly dominant species we used a modification proposed by Jones & Hargreaves (1979). If the dominant species in a quadrat represented >85% of the biomass, we allocated it to both 1st & 2nd ranks. The 2nd ranked species then dropped to 3rd , and so on, while the 6th species was not ranked. This allowed for the variation normally found in grasslands, the arbitrary limit of 85% suggested by Jones and Hargreaves to apply the correction results in proportions close to those achieved by harvesting and sorting. Calculations to determine the average biomass per site (kg.ha^{-1}) of each ranked species were performed following the methodology in t' Mannetje & Haydock (1963).

Soil sampling

Soil sampling was conducted between 28th February and 14th March 2008. Soils were sampled at the site level by taking a single soil core at each of the 30 plant quadrat sites (Fig. 2) and bulking the 30 soil samples together. Samples were taken using a soil corer to a depth of 10 cm. The internal diameter of the soil corer was 20mm with total volume of 32cm³. Before taking individual cores, the obvious undecomposed leaf, grass or other plant material on the soil was scraped away using the end of the soil corer (ie. not using any other broader implements or by hand) so that the soil surface was visible. If plant material present was decomposed and integrated into the A horizon this was included in the sample. Animal dung ie. kangaroo pellets, was specifically excluded, however soils below kangaroo dung were still collected. On the centre transect line the soil sampling point was directly below the tape measure at the appropriate distance. A toe-point method was used to locate samples away from the tape e.g. when pacing 15m from the centre transect, the point of the boot at 15m indicated exactly where to sample, with no displacement. Exceptions were when the point was directly on a live grass tussock, log, tree or rock, in which case the soil sample was taken at the closest possible area available not having these impediments.

Soil samples were dried at 38° C for 24 hrs on the day of collection to reduce microbial activity of samples, some of which were damp on sampling. They were then stored in paper bags in a dark, cool area of a laboratory until all sampling was complete and the samples sent for analysis on May 30 th 2008.

Soil analysis

Analyses were performed by the Victorian Department of Primary Industries Laboratory, Werribee, Victoria, applying the following methods to sieved (2mm) and ground samples:

Soil Colour – described on dried and ground soil in the laboratory, using Munsell Colour Charts.

Soil Texture – described on dried and ground samples (after McDonald et al. 1990).

pH – measured by two methods, in water and in $CaCl_2$ after Rayment & Higginson (1992). Only data for the $CaCl_2$ method were analysed but the results of both methods are reported in Appendix 2.

Electrical conductivity – after Rayment & Higginson (1992). Samples of <0.05 dSm^{-1} were not discriminated by the analysis.

Available phosphorus – using the Colwell method (Code no. 9B2 pg 68, Rayment and Higginson 1992). Samples of <4 mg.kg^{-1} were not discriminated by the analysis, and were given a nominal value of 2 mg.kg^{-1} where averages were required for the analyses.

Nitrate nitrogen – using method Code no. 7C2 pg 53 in Rayment and Higginson (1992). Samples of <0.25 mg.kg^{-1} were not discriminated in the analysis and were given a nominal value of 0.2 mg.kg^{-1} where averages were required for the analyses.

Total nitrogen (%) – after Rayment & Higginson (1992) The Werribee DPI lab use the FP–2000 instrument and their method was drawn from the following sources:

a) 6B3 as per Rayment & Higginson (1992). b) LECO manufacturer application note #165 at the following web address http://www.leco.com/resources/application_note_subs/pdf/organic/-165.pdf c) LECO application note # 005 http://www.leco.com/resources/application_note_subs/pdf/organic/-005.pdf

Total Carbon (%) – as for total nitrogen. Organic matter was calculated by multiplying total carbon by 1.9.

Carbon: nitrogen ratio – Total carbon divided by total nitrogen.

Data analysis

To explore the structure of the vegetation data and examine variation in relation to environmental factors, we conducted classification and ordination of the floristic data summarized at the site level. The classification of the sites was based on a matrix calculated from a Bray and Curtis dissimilarity measure (Faith et al. 1987) using the raw biomass data. We chose not to standardise the biomass data as the large range was believed to reflect strong environmental effects in the study area. Approximately one in five entries in the site by species matrix contained positive biomass estimates. A hierarchical clustering strategy was used to generate groups using the complete linkage method (equivalent to furthest neighbour method; McCune & Grace 2002). The number of groups selected was determined by inspection of the dendrogram, evaluating the height of the splits and the number and size of the groups at different levels. Groups were characterized by dominant species, soil attributes [Nitrate-N, total Carbon, total Nitrogen, organic matter, pH ($CaCl_2$), Phosphorus, Texture, Colour], landscape position of sites and ground cover variables.

Table 2. Multi-species taxa used in the survey in cases where there was ambiguity in their identification. The species that were positively identified in the survey are denoted with #. Other species are those not found or confirmed in the field, but which could possibly occur based on Lepschi (1993) and Eddy *et al.* (1998). Exotic species denoted by *.

Aira spp.
**A. cupaniana*
**A. elegantissima*

Austrodanthonia spp.
#*A. auriculata*
#*A. caespitosa*
#*A. carphoides*
#*A. eriantha*
#*A. laevis*
#*A. monticola*
#*A. penicillata*
#*A. pilosa*
#*A. racemosa*
#*A. setacea*

Cheilanthes spp.
#*C. austrotenuifolia*
C. sieberi

Cymbonotus spp.
#*C. lawsonianus*
C. preissianus

Dichelachne spp.
D. micrantha
#*D. rara*

Glycine spp.
#*G. clandestina*
#*G. tabacina*

Hordeum sp.
**H. leporinum*

Juncus subgen. *Genuini*
J. australis
J. capitatus
J. sarophorus
J. subsecundus
J. vaginatus

Lolium spp.
**L. rigidum*
#**L. perenne*

Luzula spp.
L. flaccida
L. densiflora

Thelymitra sp.
T. pauciflora

Vulpia spp.
**V. bromoides*
**V. myuros*

Wahlenbergia spp.
#*W. communis*
#*W. graniticola*
#*W. luteola*
#*W. multicaulis*
#*W. stricta*

Non-metric multidimensional scaling ordination also was performed on vegetation data using the same dissimilarity matrix as that for the classification. The ordination was evaluated by fitting a generalized additive model (GAM) surface for the continuous soil and ground cover variables and superimposing the contours over the ordination.

Two data sets were analysed. The first was biomass data for all taxa that were recorded in the survey. A second analysis was performed on the frequency data for the non-grass species only. This was to determine whether the high biomass of the grasses in the all species data set were concealing possible patterns of occurrence in the forbs that might otherwise be detected.

To explore the relationship between phosphorus and plant response, we performed regression analyses of species biomass and soil P for a selection of dominant grasses: *Aristida ramosa*, *Bothriochloa macra*, *Austrodanthonia* spp., *Elymus scaber*, *Joycea pallida*, *Microlaena stipoides*, **Phalaris aquatica*, *Austrostipa scabra* and *Themeda australis*. We explored both linear relationships and generalized additive functions for each taxon. The package R was used to conduct the classification, ordinations and regressions (R Development Core Team 2007).

Results

Growth conditions during survey and delineation of taxa

The timing of our sampling (mid-spring to the end of spring) is generally considered an optimal time to detect the maximum number of species in grassy woodlands (Burrows 2004). However, conditions leading up to the survey were dry, with below average rainfall for most months of 2007 (Table 1). Conditions were dry at the commencement of sampling in October with annuals rapidly desiccating and for the first 2–3 weeks, plants were increasingly difficult to identify. Rain started on 26th October and good rain in November 2007 allowed plant growth to be re-initiated and permitted the data collecting to be completed (Table 1).

The dry conditions and heavily grazed state of the vegetation severely limited our ability to identify species and limited our collection of voucher specimens. Nonetheless, team members were experienced, so that even poor quality material could be identified to species, species groups or generic level. These taxonomic categories are robust and will stand up in the future even under adverse growing conditions. Regardless of conditions, treatment of groups such as *Austrodanthonia* are difficult in survey work, delineation in the field is not possible even under ideal growing conditions, and the current keys do not work well with collected material. Our final categories are listed in Appendix 1, together with average biomass, cover and environmental variables at the site scale. Multiple species categories are defined in Table 2.

Table 3. Litter depth and ground cover characteristics of 961 ha sites at Mulligans Flat (n = 48) and Goorooyarroo (n = 48) Reserves. Biomass estimates are of 30 x 0.25m^2 quadrats per ha, and ground cover estimates are from four points in each of the quadrats. Bare patches are quadrats in which ≥¾ points had a litter depth of zero. SE = standard error of mean.

	Mulligans Flat		**Goorooyarroo**	
	Mean ± SE	**Range**	**Mean ± SE**	**Range**
Live plant basal area (%)	13 ± 0.9	1.7–27	12 ± 0.8	3.3–34
Litter depth where present (mm)	14 ± 0.6	6–24	11 ± 0.6	4.0–20
Bare ground (%)	16 ± 1.2	2.5–39	10 ± 0.9	1.7–27
Cryptogam (%)	7.8 ± 1.1	0–33	4.1 ± 0.5	0–17
Fallen log (%)	1.2 ± 0.3	0–7.5	1.7 ± 0.3	0–8.3
Rock (%)	0.3 ± 0.1	0–3.3	1.4 ± 0.3	0–6.7
Litter (%)	62 ± 2.5	23–87	70 ± 1.5	42–88
Bare patches (% quadrats classed as bare)	0.3 ± 0.03	0–0.7	0.15 ± 0.01	0–0.47

Ground cover and biomass attributes

The ground cover variables for each site are given in Appendix 2 and summarized in Table 3 for each reserve. Bare ground, litter and plant basal area were the dominant types of ground cover, together totalling 92% of the surveyed ground area. Fallen logs represented 1.4% of the ground cover and this represented the total of the naturally occurring timber and added timber. Mulligans Flat had more bare ground, more cryptogam cover and more bare patches, but less litter cover than Goorooyarroo. Live basal areas were similar in both reserves. Biomass data are detailed at site level in Appendix 2 and summarized in Table 4. Average total biomass for all sites was 569 kg.ha^{-1} with the highest estimates around 2,000 kg.ha^{1}. The average sward structure represents that of a grazing lawn (Fig. 1f) and in some parts of the reserve, biomass levels were exceptionally low (Fig. 1e) with the average slightly lower in Goorooyarroo.

Soil characteristics

Quantitative data characterizing each site are given in Appendix 2 and median values in Table 5. Note the following descriptions relate only to the 0–10 cm profile depth averaged over each of the 96 × 1 ha sites.

Soil colour was relatively uniform, falling into two broad groups "greyish brown / brownish grey" and "yellowish greyish brown". Their texture was predominantly sandy clay loams (81 sites) with four light-clay sites (indicating possible removal of upper horizons), and 11 sites that were silty clay or silty clay loams indicating possible deposition from higher parts of the landscape. In terms of acidity, their pH ($CaCl_2$ values) ranged from 4 to 5.2, with a median of 4.5, reflecting the natural acidity of the soil and its general limitations for intensive agriculture (Jenkins 2000). Nearly half of the sites had a pH of <4.5, a level which can be associated with aluminium toxicity (Jenkins 2000). These low values are possibly linked with prior pasture improvement in some parts of the reserves, but a clear relationship is not evident, as many sites low in P also had acid soils. Low pH also may be linked to poor litter cycling. However, the below-median pH sites were not associated with lower total carbon or high C:N ratios. This points to the occurrence of naturally extremely acid soils.

The median value of electrical conductivity was 0.05 dS.m^{-1}, with a maximum value of 0.1 indicating that soluble salts occurred at low levels at all sites. Available phosphorus values ranged from <4 to 23 mg.kg^{-1} with a median of 7 mg.kg^{-1}. Only three sites had P values over 15. Median total nitrogen was 0.14% and median nitrate was 1.0 mg.kg^{-1}. Nitrate values tended to be higher when P values were high. Total carbon median value was 2.6% and the range was 1.5–4.7%. The median carbon: nitrogen ratio was 19, with only 18 sites having values of 15–16.

Summary of ground layer vegetation

The most abundant species in terms of biomass was *Joycea pallida* followed by *Austrodanthonia* spp., *Themeda australis, Aristida ramosa, *Phalaris aquatica* and *Lomandra filiformis* (Table 6, Appendix 1). The reserves were similar in that these six were highly ranked in each, though in different order. There was considerably more *Joycea* and *Themeda* in Mulligans Flat than Goorooyarroo and the latter reserve was notable for its higher levels of **Phalaris* within the sites. There was more evenness among the dominants in Goorooyarroo, with nine species averaging over 20 kg.ha^{-1} compared with four in Mulligans Flat. There was also a greater abundance of shrubs (<0.5 m) in Mulligans Flat (*Melichrus, Lissanthe* and *Daviesia*).

Table 4. Mean, median and range of total biomass estimates (kg.ha^{-1}) for 961 ha sites and in the two reserves. Estimates were made in Spring 2007.

	Mean (±SE)	**Median**	**Range**	**No. sites >1,000 kg.ha^{-1}**	**No. sites >2,000 kg.ha^{-1}**
Mulligans Flat (n = 48)	**592±76**	**381**	**204 – 2,352**	**7**	**3**
Goorooyarroo (n = 48)	**546±45**	**430**	**289 – 1,833**	**3**	**0**
All sites (n = 96)	**569±44**	**421**	**204 – 2,352**	**10**	**3**

Table 5. Median and range of soil properties for the 96 sites. Soil samples were from 30 cores (0–10 cm) combined to characterize each 1 ha site.

	Nitrate-N (mg.kg^{-1})	**Total carbon (%)**	**Total nitrogen (%)**	**C:N ratio**	**Electrical conductivity (dS.m^{-1})**	**pH ($CaCl_2$)**	**Available phosphorus (mg.kg^{-1})**
Median	1.0	2.6	0.14	19.0	0.05	4.5	7
Max.	11	4.7	0.3	31.5	0.11	5.2	23
Min.	<0.25	1.5	0.07	14.8	<0.05	4	<4

Trees and shrubs

While the scale of sampling was not designed for trees and shrubs, we did count eucalypt suckers and seedlings less than 0.5 m high in the quadrats, recording an average density of 875 per ha of which 94% were *Eucalyptus blakelyi*, 3% were *Eucalyptus macrorhyncha*, 1.6% *Eucalyptus mannifera* and 1.6% *Eucalyptus melliodora*. Given that *Eucalyptus melliodora* was the co-dominant adult tree alongside *Eucalyptus blakelyi* (data not presented), these results indicate the prolific regeneration of *Eucalyptus blakelyi*.

Shrubs >0.5 m high were also counted but only three species were recorded: *Acacia dealbata* (222 ha^{-1}), *Acacia parramattensis* (97 ha^{-1}), and *Daviesia mimosoides* (28 ha^{-1}). The two *Acacia* species were also recorded as plants <0.5 m high among the dominants in the biomass assessments, but at extremely low frequencies occurring in only three quadrats (of a total of 2,880 quadrats), suggesting a very low density of recruitment.

Additional species of shrub were recorded in the quadrats as less than 0.5m high, and these were sub-shrubs that are generally of low stature, most commonly *Melichrus urceolatus*, *Daviesia genistifolia* and *Lissanthe strigosa*. Other shrubs recorded in Mulligans Flat but which did not fall into the quadrat samples included: *Acacia implexa*, *Acacia mearnsii*, *Acacia decurrens*, *Cassinia* spp, *Daviesia leptophylla*, *Exocarpos cupressiformis* and *Indigofera australis* and are locally uncommon to rare in the reserves (Lepschi 1993).

Patterns in the ground layer vegetation

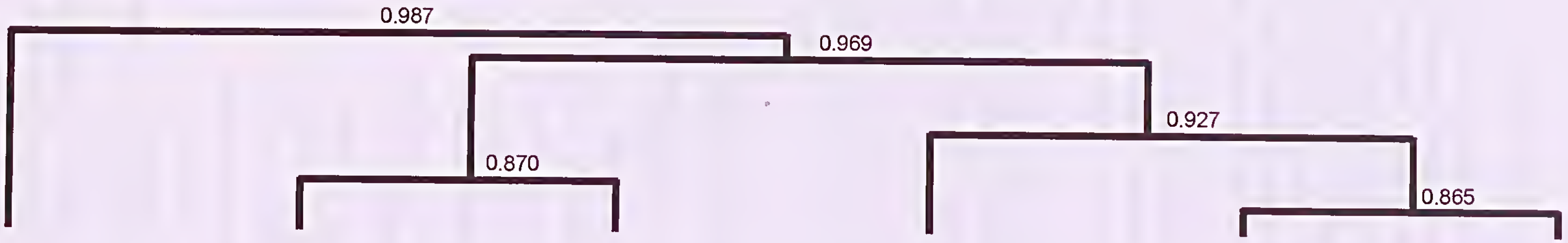
The classification of the 96 sites, based on the biomass of all plant taxa recorded, produced six groups that met our subjective criteria and which were ecologically interpretable. These are described floristically in Table 7 and summarized in terms of physical characteristics in Fig. 3. Group 2 (named *Austrodanthonia* – lawn) comprised nearly half the sites, and appears to represent the typical ground layer vegetation in not being distinctively different from the 'average' floristic composition (Table 6) apart from a paucity of *Joycea*. This group was found in all landscape positions, and had soil attributes that were generally intermediate in value, but tending towards low biomass and available phosphorus.

The next largest group was typified as *Themeda* lawn (Group 4), low biomass areas dominated by *Themeda* with moderate phosphorus levels, relatively elevated pH, low nitrates and a low carbon nitrogen ratio. Two other *Austrodanthonia*-dominated groups appeared to have had a history of pasture development, occurring on lower and mid-slopes, with elevated phosphorus and nitrate levels: Group 1 (**Phalaris* co-dominance, Fig. 1d) was associated with the highest P

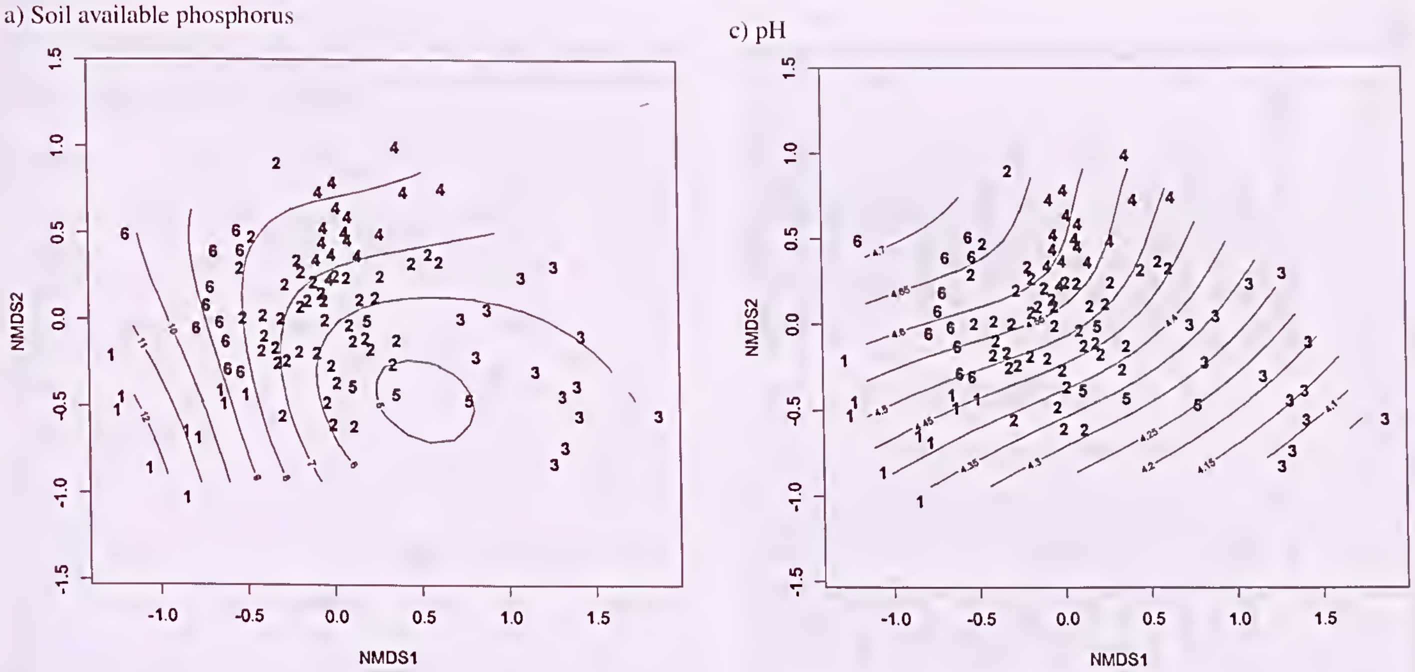
Table 6. Average biomass (kg.ha^{-1}) for 20 most abundant taxa recorded in all 1 ha sites and in the two reserves.

All sites		Goorooyarroo		Mulligan's Flat	
Joycea pallida	143	*Austrodanthonia* spp.	125	*Joycea pallida*	240
Austrodanthonia spp.	111	*Joycea pallida*	45	*Austrodanthonia* spp.	97
Themeda australis	50.6	*Aristida ramosa*	41.7	*Themeda australis*	62.6
Aristida ramosa	35.1	*Themeda australis*	38.5	*Aristida ramosa*	28.5
**Phalaris aquatica*	23.8	**Phalaris aquatica*	36.5	*Lomandra filiformis*	18.1
Lomandra filiformis	19.9	*Austrostipa densiflora*	34.1	*Melichrus urceolatus*	13.7
Bothriochloa macra	17.4	*Bothriochloa macra*	27.7	**Phalaris aquatica*	11.2
Austrostipa densiflora	17.2	*Austrostipa scabra*	23.8	*Lissanthe strigosa*	10.1
Austrostipa scabra	14.4	*Lomandra filiformis*	21.7	*Bothriochloa macra*	7.1
**Trifolium subterraneum*	10.5	**Lolium* spp.	18.2	*Microlaena stipoides*	6.5
Elymus scaber	10.3	**Trifolium subterraneum*	16.6	*Daviesia genistifolia*	6.3
**Lolium* spp.	10.2	*Elymus scaber*	15.7	*Austrostipa scabra*	5.1
Melichrus urceolatus	9.2	*Austrostipa bigeniculata*	13.4	*Elymus scaber*	4.9
Microlaena stipoides	7.0	*Microlaena stipoides*	7.5	*Poa sieberiana*	4.7
Lissanthe strigosa	6.9	**Arctotheca calendula*	6.3	**Trifolium subterraneum*	4.3
Austrostipa bigeniculata	6.7	*Melichrus urceolatus*	4.7	*Juncus* subgen. *Genuini*	4.0
Poa sieberiana	4.4	*Poa sieberiana*	4.2	*Gonocarpus tetragynus*	3.6
**Arctotheca calendula*	3.5	*Lissanthe strigosa*	3.7	*Vittadinia muelleri*	3.3
Daviesia genistifolia	3.1	**Bromus hordeaceus*	3.4	*Hydrocotyle laxiflora*	2.9
Juncus subgen. *Genuini*	2.9	**Poa bulbosa*	2.8	*Solenogyne dominii*	2.6

Fig 3. Dendrogram showing the relationship between the six floristic groups which are characterized by landscape position, average total biomass (with standard error), ground cover, soil properties (medians in brackets) and proportional representation of sites in Mulligans Flat (MF) and Goorooyarroo (Gooroo) Reserves. Floristic features of the groups are described in Table 7. Dissimilarity values for the top five fusions in the dendrogram are given at the points of fusion.



Joycea – large tussocks	*Austrodanthonia* - fertilized	**Phalaris* - fertilized	*Themeda* - lawn	*Joycea* - shrubby	*Austrodanthonia* - lawn
Group 3 (13 sites)	Group 6 (11 sites)	Group 1 (10 sites)	Group 4 (16 sites)	Group 5 (4 sites)	Group 2 (42 sites)
All on slopes (no flats)	Lower- to mid-slopes	Lower-slopes	All on slopes (no flats)	Lower-slopes	All landscape positions
V. high biomass (1346 ± 176 kg.ha^{-1})	Low biomass (351 ± 16)	High biomass (817 ± 144)	Low biomass (352 ± 33)	Average biomass (521 ± 52)	Low biomass (413 ± 23)
High basal areas, thick litter	High basal areas, thin litter, low bare ground	High basal areas, thick litter, low bare ground	Low basal areas	High cryptogam cover, thick litter	Average values
Phosphorus low (6 mg.kg^{-1})	P moderate (7)	P high (12)	P moderate (8)	P moderate (7)	P low (5)
Nitrate low (0.5 mg.kg^{-1})	Nitrate high (5.2)	Nitrate highest (7.9)	Nitrate low (0.55)	Nitrate low (0.58)	Nitrate mod. low (0.8)
pH very low (4.1)	pH moderate (4.5)	pH mod. low (4.35)	pH high (4.6)	pH moderate (4.45)	pH moderate (4.5)
C:N ratio high (23)	C:N ratio low (17)	C:N ratio low (17)	C:N ratio low (17)	C:N ratio high (23)	C:N ratio moderate (19)
77% in MF; 23% in Gooroo	100% in Gooroo	10% MF; 90% Gooroo	75% MF; 25% Gooroo	100% MF	50% MF; 50% Gooroo


a) Soil available phosphorus

c) pH

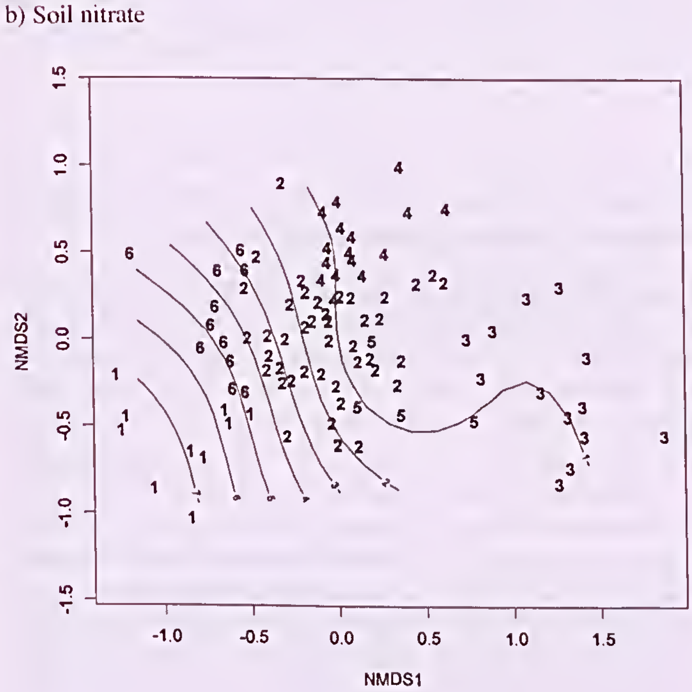

b) Soil nitrate

Fig. 4. Non-metric multidimensional scaling ordination of the 96 sites based on biomass estimates for all species with contour lines showing the GAM fitted surface for a) soil available phosphorus (mg.kg^{-1}) b) nitrate (mg.kg^{-1}) and c) soil pH. The large bold numbers indicated the position of sites in the ordination space and the group affinity of the sites at the six group level (see Figure 3).

levels and more acidic soil, while Group 6 had lower levels of P and higher pH and was co-dominated by **Trifolium subterraneum*. The most distinctive group was *Joycea*-dominated slopes (Group 3, Fig. 1c), characterized by the most acidic soils, the highest biomass, the highest carbon nitrogen ratio and low phosphorus and nitrate levels. One small group (Group 5, comprising 4 sites) was also dominated by *Joycea* and had a high shrub component (*Daviesia* most abundant), but only average total biomass and more moderate soil properties. The significance of this group is unknown.

The generalized surfaces fitted to the NMDS axes 1 and 2 scores are shown in Fig. 4 for soil available phosphorus, soil nitrate and pH. The surfaces for soil phosphorus and soil nitrate were complex with strong gradients in both nutrients along the first axis but with interactions with the second axis. The relationship between pH and the first two axes scores is less complex, broadly showing the majority of the sites in Groups 3 have the lowest pH values and groups 1, 6 and 4 tending to occur in areas with intermediate to high pH values.

The classification of the sites based on the frequency data of non-grass (forb) taxa did not produce groups that were an improvement on the 'all-species' biomass data. However, the ordination with a generalized additive model surface fitted for nitrates revealed a strong relationship between the ordination of the forb frequency data and soil nitrates. We have represented this relationship in terms of proportion of exotic species represented in the forb biomass (Figure 5), as there is a strong positive relationship between nitrates and exotics, most of which are annual species.

Soil phosphorus and abundance of dominant grasses

Based on linear regression analysis four of the nine grasses showed a significant relationship to available soil phosphorus (P) levels (Table 8). *Elymus scaber*, **Phalaris aquatica* and *Austrostipa scabra* show a positive relationship; as phosphorus levels increased so did the biomass. *Aristida ramosa* showed a negative relationship to phosphorus.

Table 7. The identity and mean biomass (kg.ha⁻¹) of the fifteen most abundant species per site for the six groups identified from a classification of 96 x 1 ha sites in Mulligans Flat and Goorooyarroo nature Reserves. Classification was based on the average biomass per site of all plant taxon groups that were ranked 1–6 in 30 quadrats. Note Group 3 is the most distinct group in the dendrogram (Fig. 3), groups 1 and 6 are closely-related, groups 2 and 5 are closely-related. Group 4 is more closely-related to the combined groups 2 and 5 than to the other groups.

***Phalaris* – fertilized**		***Austrodanthonia* – lawn**		***Joycea* – large tussocks**		***Themeda* – lawn**		***Joycea* – shrubby**		***Austrodanthonia* – fertilized**	
Group 1 (10 sites)		**Group 2 (42 sites)**		**Group 3 (13 sites)**		**Group 4 (16 sites)**		**Group 5 (4 sites)**		**Group 6 (11 sites)**	
Austrodanthonia spp.	259	*Austrodanthonia* spp.	122	*Joycea pallida*	986	*Themeda australis*	142	*Joycea pallida*	145	*Austrodanthonia* spp.	79
**Phalaris aquatica*	195	*Aristida ramosa*	53	*Aristida ramosa*	72	*Austrodanthonia* spp.	62	*Austrodanthonia* spp.	119	**Trifolium subterraneum*	52
Austrostipa scabra	75	*Themeda australis*	36	*Themeda australis*	64	*Lomandra filiformis*	19	*Daviesia genistifolia*	62	*Bothriochloa macra*	29
**Lolium* spp.	60	*Austrostipa densiflora*	30	*Austrodanthonia* spp.	48	*Bothriochloa macra*	12	*Melichrus urceolatus*	35	**Phalaris aquatica*	22
Elymus scaber	49	*Bothriochloa macra*	25	*Melichrus urceolatus*	45	*Austrostipa scabra*	9.5	*Themeda australis*	31	*Lolium* spp.	20
Austrostipa bigeniculata	46	*Lomandra filiformis*	21	*Lomandra filiformis*	37	*Poa sieberiana*	7.4	*Lomandra filiformis*	18	*Elymus scaber*	17
Microlaena stipoides	20	*Lissanthe strigosa*	13	*Austrostipa densiflora*	8	*Aristida ramosa*	6.9	*Aristida ramosa*	14	*Austrostipa densiflora*	13
**Arctotheca calendula*	14	*Austrostipa scabra*	8.7	*Brachyloma daphnoides*	6.5	*Lissanthe strigosa*	5.8	*Bothriochloa macra*	12	*Lomandra filiformis*	11
**Trifolium subterraneum*	14	*Joycea pallida*	6.0	*Poa sieberiana*	6.2	*Microlaena stipoides*	5.6	*Vittadinia muelleri*	7.8	**Arctotheca calendula*	10
Austrostipa densiflora	12	*Microlaena stipoides*	5.7	*Gonocarpus tetragynus*	5.5	*Leptorhynchos squamatus*	5.5	**Trifolium subterraneum*	5.7	*Themeda australis*	9.3
**Bromus diandrus*	8.6	**Trifolium subterraneum*	5.2	*Goodenia hederacea*	3.6	*Enneapogon nigricans*	5.4	**Trifolium dubium*	4.8	*Panicum effusum*	8.8
Einadia nutans	7.8	*Poa sieberiana*	5.0	*Dillwynia sericea*	3.5	*Juncus* subgen. *Genuini*	5.4	*Panicum effusum*	4.7	*Austrostipa scabra*	8.6
**Hordeum* ∞–	5.6	*Elymus scaber*	4.8	**Hypochaeris radicata*	3.1	*Elymus scaber*	5.2	*Gonocarpus tetragynus*	4.6	*Microlaena stipoides*	8.6
Bothriochloa macra	5.4	*Melichrus urceolatus*	3.3	**Trifolium striatum*	2.8	*Joycea pallida*	4.4	*Lissanthe strigosa*	3.8	**Bromus hordeaceus*	8.3
**Bromus hordeaceus*	4.8	*Tricoryne elatior*	3.1	*Microlaena stipoides*	2.5	*Vittadinia muelleri*	4.2	*Poa sieberiana*	3.5	*Austrostipa bigeniculata*	7.6

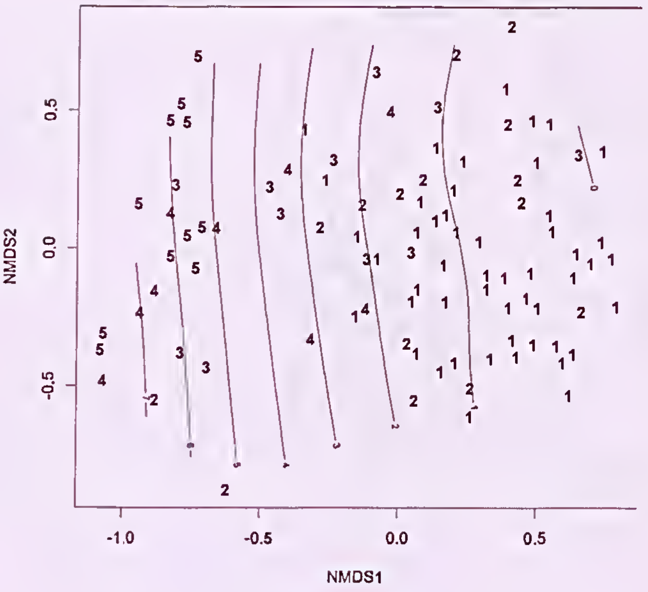


Fig. 5. Non-metric multidimensional scaling ordination of the frequency of non-grass species with contour lines showing the GAM fitted surface for soil nitrates (mg.kg⁻¹). Sites are coded by the proportion of biomass that is exotic. 1 = 0 – 20%; 2 = 20 – 40%; 3 = 40 – 60%; 4 = 60 – 80%; 5 = 80 – 100%.

Microlaena stipoides showed a weaker but positive relationship between phosphorus and biomass.

From diagnostic plots of the linear regressions it was clear that the relationships between species biomass and soil phosphorus levels were more complex than simple straight line relationships. These were explored using generalized additive models. GAMs were fitted using penalized regression splines with smoothing parameters selected by generalized cross validation (Cook 2006). Using this approach the same four species as noted in Table 8 showed significant relationships. An additional species, *Microlaena stipoides*, now exhibited a complex relationship between soil phosphorus and biomass. The generalized additive model for *Microlaena stipoides* was complex with local maxima and minima along the phosphorus gradient suggesting that there was a range of other factors influencing this species.

Aristida ramosa had a significant negative relationship with P, with an average biomass of 65 kg.ha⁻¹ at low P (0–6 mg.kg⁻¹) compared with 12 kg.ha⁻¹ at higher P (7–23 mg.kg⁻¹). While *Joycea pallida* had a non-significant relationship, it too is generally considered to be a P sensitive species (McIntyre 2008; Fig. 4a), and had biomass values of 230 (0–6 mg.kg⁻¹) and 76 (7–23 mg.kg⁻¹). *Bothriochloa macra* occurs over the range of P levels, but had a slight (non-significant) decline as P increased. *Elymus scaber* had a significant but weak increase with increasing P, but was most abundant between 8–13 mg.kg⁻¹. In a similar way, *Themeda australis* whilst having a non-significant linear relationship with P, was most abundant in the 5–10 mg.kg⁻¹ range. *Microlaena stipoides*

Table 8. Linear regression coefficients, standard error and F ratio statistics for regressions relating species biomass (kg. ha^{-1}) and available soil phosphorus (mg.kg^{-1}) with significant relationships highlighted in bold.

Species	Intercept	Slope	s.e.	F ratio	P
Aristida ramosa	88	-7.3	1.4	25	<0.001
Bothriochloa macra	21	-0.5	0.82	0.38	0.54
Austrodanthonia spp.	97	2.0	3.3	0.36	0.55
Elymus scaber	-3.1	1.8	0.68	7.2	0.009
Joycea pallida	269	-17	12	2.0	0.16
Microlaena stipoides	2.6	0.59	0.35	2.9	0.092
**Phalaris aquatica*	-60	11	2.4	23	<0.001
Austrostipa scabra	-14	3.9	0.74	28	<0.001
Themeda australis	46	0.65	2.17	0.089	0.77

had some positive relationship with P, but occurred across the range of values. **Phalaris* had a strong and significant positive relationship, as would be expected of an introduced pasture grass, but it was too infrequent to enable its response to be characterized. The group of pooled *Austrodanthonia* species did not exhibit significant or interpretable response to P, but this is unsurprising considering the group is comprised of at least ten species (Table 2).

Discussion

Patterns in groundlayer vegetation

The site locations for the experiment aimed to capture box-gum woodland on the better soils, so that our description cannot claim to be characteristic of the entire landscape, as the stony ridge tops dominated by *Eucalyptus mannifera* and *Eucalyptus rossii* were excluded, although these two eucalypts were recorded in low numbers in the sites. Nonetheless, a range of slope positions was still represented in the sites, but there was only weak evidence of changes in the ground layer vegetation linked to this (*Themeda* and *Joycea* were less dominant on the flats). Phosphorus, nitrates and pH appeared to more strongly characterize the differences between floristic groups, both delineating the weed dominated vegetation (see below) and the native dominated groups. *Joycea* dominance was associated with the most acidic soil, *Themeda* dominated where phosphorus and pH was slightly higher and *Austrodanthonia* was dominant at sites intermediate in pH, low in P and slightly higher in nitrates. We found forb composition to be particularly sensitive to nitrates.

Sub-shrubs (<0.5 m) had a significant presence in few sites and even in these, their biomass was not particularly high (Group 5, Table 7). The three most abundant taller shrubs (*Acacia dealbata*, *Acacia parramattensis*, and *Daviesia mimosoides*) do not have strong presence in the study area overall, and collectively, their regeneration was sparse (300–400 plants per ha , <0.5 m tall). Based on observations on other parts of the district, we would predict that with reduced grazing pressure, an increase in all shrubs would be expected.

Evidence of past disturbances

The soil attributes of the reserves are consistent with native soils that are naturally acid, and low in phosphorus and nitrogen (Prober et al. 2002a) although there is some evidence of past disturbances in the form of pasture development. There are areas with elevated phosphorus and nitrates, and the floristics of these was consistent with a history of past fertilization and sowing of exotic species. **Phalaris* was associated with the highest levels of available phosphorus (Group 1, Fig. 3, Table 6) and as this species does not generally establish or persist on highly acid, infertile soils (Keys 1996) its dominance is taken as an indication of locations of previous pasture development rather than being viewed as an active invader. Another set of sites dominated by *Austrodanthonia* and **Trifolium subterraneum* (Group 6, Fig. 3, Table 6) is also likely to have had a history of fertilization, with elevated levels of P and high levels of nitrate. The presence of annuals such as **Trifolium subterraneum* is considered to be a barrier to native perennial restoration as annual patterns of release and recapture of nitrates creates a positive feedback loop that encourages continuing dominance of annual plants (Prober et al. 2002b). There were 19 sites (20% of the total) with available P levels of 10 mg.kg^{-1} or more and which are likely to have been fertilized in the past. A more extensive area may have been fertilized but has now recovered levels close to those of native soils. Available phosphorus tends to become unavailable over time due to immobilization in the soil. Given the linear positive relationship between **Phalaris* and P, we predict that over time, this grass will decline in the reserves. Other exotics such as **Trifolium* spp. and the annual grasses are predicted to persist as annual nitrate release is more likely to be ongoing.

The effects of past livestock grazing are confounded with the current impacts of macropod grazing, but the current levels of ground cover are moderately high (at least compared to commercial pasture management standards) with about 13% bare ground, and cover consisting primarily of litter, plant basal area and cryptogams. Over 30% bare ground is considered to leave grassland vulnerable to soil erosion (McIvor 2002), so in terms of cover, we consider the soil to be generally stable. We did not measure sorbtivity or infiltration, and visual observation would suggest there are significant areas of low infiltration in parts of the landscape, with the possible suggestion that this has been the result of livestock trampling and grazing, and subsequent erosion in the past. The difficulty with such measures, is that we do not have reference conditions for whole landscapes of this type, and that the inherently poor soils may have originally had areas of low infiltration in the past, with a mosaic of run-off and run-on areas. A possible scenario is that past livestock grazing has coarsened the spatial scale of any natural patchiness in the landscape and it could be hypothesized that these will become more fine-scale with ongoing relief from heavy grazing pressure.

Total carbon values were comparable to those of reference woodland in sites under trees (Prober et al. 2002a). These values tend to be slightly lower in open areas (Prober et al. 2002a), although this patterning is not evident in our study as open and canopy areas were not differentiated at the quadrat level. The carbon: nitrogen ratios for Goorooyarroo and Mulligans Flat were high (median 19) even compared to below canopy values in reference woodlands (16 under trees, 15 in the open). Certainly the accumulation of woody debris and leaf litter is very evident under the larger trees in the reserves, and the accumulation of carbon and litter would be expected over the life of a eucalypt. The question is whether these higher ratios are an indication of abnormally low rates of litter recycling due to past erosion events removing topsoil. If this were the case, we would predict slight reductions in the C:N ratio in coming years, assuming the potential impacts of heavy grazing are controlled.

Sward structure and current grazing pressure

An intended outcome for these reserves is to restore ecosystem structure and function sufficiently to enable a range of fauna to re-colonize, either naturally or with assistance. Two methods planned to achieve this is active addition (and natural accumulation) of fallen timber (coarse woody debris) and the control of total grazing pressure. Managed fire is also being considered both as a fuel reduction tool and potential conservation tool, although its role in this ecosystem is not well understood.

Kangaroo densities in the ACT generally are extremely high and have been recorded at 233 km^{-2} in ACT reserves, the highest densities in south-eastern Australia (Kangaroo Advisory Committee 1996). Kangaroo density in Goorooyarroo was estimated at approximately 195 km^{-2} (summer 2007, Howland 2009) and 142 km^{-2} in Mulligans Flat (winter 2008, B. Howland *unpublished data*). Our biomass estimates, which are an indicator of grazing pressure, are consistent with these high kangaroo densities. The overall average biomass that we measured (570 $kg.ha^{-1}$) would represent a short lawn if dominated by *Themeda* (Fig. 1f) and can be much shorter over large areas (Fig. 1e). There were high biomass sites in the reserves, but these were associated with the dominance of *Joycea*, an extremely coarse, unpalatable large tussock grass (Fig. 1c), and its presence does not necessarily indicate areas of lower grazing pressure.

McIntyre & Tongway (2005) determined that grazing lawns are well below optimal condition from the point of view of soil health (nutrient cycling, infiltration). In sub-tropical grassy woodlands, 750 $kg.ha^{-1}$ would be needed to protect pastures from spring storms (Partridge 1993), and this is higher than the average biomass in our study. The presence of cryptogams and litter plays a significant role in stabilizing the soil surface (Tongway & Hindley 1995). While the presence of kangaroos instead of livestock would have encouraged the development of these protective cryptogam and litter layers, extremely high numbers of kangaroos can still damage them, and this can be observed elsewhere in the ACT.

A lawn sward structure is also sub-optimal from the perspective of fauna habitat (McIntyre 2005) and a variety of structures and ground cover types is considered to be better for faunal persistence. Fortunately, the *Joycea* tussocks avoided by grazers can provide some protection for fauna in the reserves in the face of high grazing. We do not know whether this can substitute entirely for the loss of tussock structure cause by the grazing of other large tussock species (e.g. *Aristida*, *Themeda*, *Poa*). Clearly reduction of kangaroo densities will be an important treatment for the experiment, and an ongoing issue for the reserves overall.

Limitations and strengths of the survey

Our floristic description of the vegetation was necessarily restricted, owing to the seasonal conditions which were initially dry, and to the short duration of our observations (six weeks). The latter feature was necessary to provide a comparable snapshot of biomass across the treatments. The result has been that we have not adequately detected early season geophytes such as orchids and lilies which are sensitive to seasonal conditions and become difficult to detect by late spring. Similarly, we have probably underestimated the biomass of some late season, C_4 grasses such as *Bothriochloa*, *Chloris*, *Panicum* and *Eragrostis*. We sampled few species that had not been recorded by Lepschi (1993) who searched monthly throughout the year. Our sampling protocol also has restricted our ability to compare species richness with other studies, owing to the use of only the top six ranked species per quadrat. However, site-scale comparisons of richness will be possible with subsequent surveys using the same methods.

While previous surveys of grassland conducted by the first author elsewhere have been more taxonomically explicit, and covered larger areas, they have also spanned more than one season and up to five months in a season, and have not estimated biomass (McIntyre et al. 1993; 2002). In all three surveys, there has been a need to use multiple species groups, as so many taxa require good flowering and/or seeding material for identification and this needs to be available in, or very near, a quadrat. Even with adequate material, identification of some groups requires collection, microscopic examination and consultation with specialists (e.g. *Austrodanthonia*, *Wahlenbergia*, **Hordeum*, *Eragrostis*, *Aristida*). Beyond this, it may still not be possible to identify all material owing to difficulties with regional variation within and intergrading of characters. Particularly problematic is *Austrodanthonia*, as they are so abundant and vary greatly in their ecological responses (Scott & Whalley 1982). There appears no easy solution to these problems which can only be addressed with rigorous collecting and a long-developed familiarity with field characters of local plant assemblages.

Conclusions

Although there have been limitations imposed on this study, we have established a relatively robust and repeatable methodology, that has struck a reasonable balance of floristic and physical attributes. The resulting baseline data set provides a strong foundation for monitoring of ecological and broad floristic changes in the reserves over the medium to long-term. Floristic patterns and soil properties indicate areas of previous pasture improvement and some patterns of native grass dominance that are linked primarily to variation in pH and phosphorus. Our results are consistent with a conclusion that the reserves are being subjected to extremely high grazing pressures throughout, sufficient to affect soil processes and the value of the grassy sward structure as habitat. Continued high levels of grazing may inhibit soil, water and nutrient processes essential for restoration of well-functioning grassy woodlands. In the absence of reference conditions, it is not possible to understand, in detail, the soil and vegetation properties that management should be aiming to restore, and a search for reference sites on comparable soils is needed. Other important information that has not been provided in this study, and which could be considered for subsequent studies include: i) direct assessments of soil function such as stability, infiltration and nutrient cycling (Tongway & Hindley 1995); ii) detailed studies of *Austrodanthonia* occurrence and ecology and; iii) surveys and grazing response studies of winter-growing and early spring-flowering species such as geophytes and orchids.

Acknowledgments

The research site has been established with the funding provided by the ACT Government and the Australian Research Council (Linkage Grant LP0561817). The survey was funded though the National Heritage Trust Program (Project 18150) and the Caring for our Country Initiative (Project 2705) with the support of the ACT Natural Resource Management Council. We thank Cam McDonald for the supply of the computational spreadsheet for BOTANAL analysis and much useful advice. Peter Mills provided logistic assistance in the reserves and David Tongway helped in the interpretation of the soil results. Ross Cunningham and Jeff Wood provided input into the experimental design.

References

Burrows, G.E. (2004) The importance of seasonality in the timing of flora surveys in the South and Central Western Slopes of New South Wales. *Cunninghamia* 8: 514–520.

Caughley, G., Grigg, G., Caughley J, Hill G.J.E. (1980) Does dingo predation control the densities of kangaroos and emus? *Australian Wildlife Research* 7: 1–12.

Cook, S.M. (2006) *Generalized additive Models: An introduction with R.* (Chapman & Hall/CRC: Boca Raton).

Eddy, D., Mallinson, D., Rehwinkel, R. & Sharp, S. (1998) *Grassland flora: a field Guide for the Southern Tablelands (NSW & ACT).* (Environment ACT: Canberra).

Faith, D.P., Minchin, P.R. & Belbin, L. (1987) Compositional dissimilarity as a robust measure of ecological distances. *Vegetatio*, 69: 57–68.

Howland, B. (2009) *Pellet Count Techniques for Estimating the Abundance of Eastern Grey Kangaroos in the ACT.* (B. Sc. (Hons) Thesis, Australian National University).

Jenkins, B.R. (2000) *Soil Landscapes of the Canberra 1:100 000 Sheet* (Dept. of Land and Water Conservation: Sydney)

Jones, R.M., Hargreaves, J.N.G. (1979) Improvements to the dry-weight-rank method for measuring botanical composition. *Grass and Forage Science* 34, 181–189.

Kangaroo Advisory Committee (1996) *Living with Kangaroos in the ACT: Rural Lands* (First Report to the Minister for the Environment Land and Planning, Canberra).

Keys, M.J. (1996) *Management of Profitable and Sustainable Pastures* (NSW Agriculture: Queanbeyan).

Lepschi, B.J. (1993) Vegetation of Mulligans Flat, A.C.T. *Cunninghamia* 3: 155–166.

McCune, B. & Grace, J.B. (2002) *Analysis of Ecological Communities* (MJM Software Design: Oregon).

McDonald, R.C. & Isbell, R.F., Speight, J.G., Walker, J. & Hopkins, M.S. (1990) *Australian Soil and Land Survey. Field Handbook* (Inkata Press: Melbourne).

McIntyre, S. (2005) Biodiversity attributes of different sward structures in grazed grassland. *Ecological Management and Restoration* 6: 71–73.

McIntyre, S. (2008) The role of plant leaf attributes in linking land use to ecosystem function and values in temperate grassy vegetation. *Agriculture, Ecosystems and Environment* 128: 251–258.

McIntyre, S., Huang, Z. & Smith, A.P. (1993) Patterns of abundance in grassy vegetation of the New England Tablelands: identifying regional rarity in a threatened vegetation type. *Australian Journal of Botany* 41: 49–64.

McIntyre, S., Heard, K.M. & Martin, T.G. (2002) How grassland plants are distributed over five human-created habitats typical of eucalypt woodlands in a variegated landscape. *Pacific Conservation Biology* 7, 274–285.

McIntyre, S. & Lavorel, S. (2007) A conceptual model of land use effects on the structure and function of herbaceous vegetation. *Agriculture, Ecosystems and Environment* 119, 11–21.

McIntyre, S. & Tongway, D. (2005) Grassland structure in native pastures: links to soil surface condition. *Ecological Management & Restoration* 6, 43–50.

McIvor, J.G. (2002) Soils, pp. 41–59 in McIntyre, S., McIvor, J.G. & Heard, K.M. (eds) *Managing & Conserving Grassy Woodlands* (CSIRO Publishing: Melbourne).

Partridge, I. (1993) *Managing southern Speargrass: A Grazier's Guide* (Queensland Department of Primary Industries: Brisbane).

Prober, S.M., Lunt, I.D. & Thiele, K.R. (2002a) Determining reference conditions for management and restoration of temperate grassy woodlands: relationships among trees, topsoils and understorey flora in little-grazed remnants. *Australian Journal of Botany* 50, 687–697.

Prober, S.M., Thiele, K.R. & Lunt, I.D. (2002b) Identifying ecological barriers to restoration in temperate grassy woodlands: soil changes associated with different degradation states. *Australian Journal of Botany* 50, 699–712.

R Development Core Team (2007) *R: A Language and Environment for Statistical Computing* (R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org [verified 09/12/2008]).

Rayment, G.E., Higginson, F.R. (1992) *Australian Laboratory Handbook of Soil and Water Chemical Methods* (Inkata Press, Melbourne).

Scott, A.W. & Whalley, R.D.B. (1982) The distribution and abundance of species of Danthonia DC on the New England Tablelands (Australia). *Australian Journal of Ecology* 7, 239–248.

Scott, D. (1986) Coefficients for the dry-weight rank method of botanical analysis of pasture. *Grass and Forage Science* 41, 319–321.

Sleeman, J.R., Walker, P.H. (1979) *The Soils of the Canberra District* (CSIRO: East Melbourne).

t' Mannetje, L. & Haydock, K.P. (1963) The Dry-Weight-Rank Method for the botanical analysis of pasture. *Journal of the British Grassland Society* 18, 268–275.

Tongway, D. & Hindley, N. (1995) *Manual for Soil Condition Assessment of Tropical Grasslands* (CSIRO Division of Wildlife and Ecology: Canberra)

Tothill, J.C., Hargreaves, J.N.G., Jones, R.M. & McDonald, C.K. (1992) 'BOTANAL – *A Comprehensive Sampling and Computing Procedure for Estimating Pasture Yield and Composition. 1. Field Sampling* (CSIRO Division of Tropical Crops and Pastures, Brisbane)

Viggers, K.L. & Hearn, J.P. (2005) The kangaroo conundrum: home range studies and implications for land management. *Journal of Applied Ecology* 42, 99–107.

Manuscript accepted 16 February 2010

Appendix 1.

Summary of plant data in 96 × 1 ha sites, giving frequency (n = 96) and average biomass (n = 96) of all plant taxa recorded in the survey a) native species; b) exotic species ranked alphabetically.

a) Native plant species	**Family**	**Frequency (% of plots)**	**Average biomass (kg ha^{-1})**
Acacia dealbata	FAB	2	0.14
Acacia gunnii	FAB	2	0.02
Acacia parramattensis	FAB	1	0.06
Acaena ovina	ROS	51	2.1
Alternanthera sp. A	POLYGON	13	0.02
Aristida ramosa	PO	70	35.1
Arthropodium minus	ANTHERIC	21	0.12
Asperula conferta	RUBI	23	0.42
Astroloma humifusum	EPACRID	2	0.17
Austrodanthonia spp.	PO	100	111
Austrostipa bigeniculata	PO	14	6.7
Austrostipa densiflora	PO	27	17.2
Austrostipa scabra	PO	69	14.4
Bossiaea buxifolia	FAB	7	0.23
Bossiaea prostrata	FAB	13	0.17
Bothriochloa macra	PO	68	17.4
Brachyloma daphnoides	FAB	1	0.89
Bulbine bulbosa	ASPHODEL	9	0.18
Carex inversa	CYPER	37	0.54
Chamaesyce drummondii	EUPHORBI	17	0.14
Cheilanthes spp.	SINOPTERID	35	0.38
Chloris truncata	PO	30	1.2
Chrysocephalum apiculatum	ASTER	6	0.59
Chrysocephalum semipapposum	ASTER	2	0.02
Convolvulus angustissimus	CONVOLUL	18	0.28
Cotula australis	ASTER	7	0.01
Craspedia variabilis	ASTER	13	0.25
Crassula sieberiana	CRASSUL	38	0.22
Cymbonotus spp.	ASTER	11	0.11
Cynodon dactylon	PO	2	0.002
Cynoglossum suaveolens	BORAGIN	4	0.03
Daucus glochidiatus	API	44	0.20
Daviesia genistifolia	FAB	10	3.1
Desmodium varians	FAB	43	0.50
Dianella revoluta	PHORMI	1	0.09
Dichelachne spp.	PO	3	0.03
Dichopogon fimbriatus	ANTHERIC	9	0.15
Dillwynia sericea	FAB	10	1.0
Diuris sulphurea	ORCHID	2	0.12
Drosera peltata	DROSER	2	0.01
Einadia nutans	CHENOPODI	13	1.5
Eleocharis acuta	CYPER	2	0.05
Elymus scaber	PO	95	10.3
Enneapogon nigricans	PO	16	1.1
Eragrostis brownii	PO	11	0.07
Erodium crinitum	GERANI	2	0.01
Eryngium rostratum	API	1	0.02

Euchiton gymnocephalus	ASTER	5	0.01
Euchiton sphaericus	ASTER	6	0.01
Galium gaudichaudii	RUBI	1	0.01
Geranium solanderi	GERANI	34	0.30
Glycine spp.	FAB	19	0.22
Gonocarpus tetragynus	HALORAG	73	2.4
Goodenia hederacea	GOODENI	45	0.88
Goodenia pinnatifida	GOODENI	7	0.11
Haloragis heterophylla	RUBI	45	0.72
Hibbertia obtusifolia	DILLENI	8	0.45
Hovea heterophylla	FAB	3	0.07
Hydrocotyle laxiflora	API	65	1.9
Hypericum gramineum	CLUSI	48	0.55
Isoetopsis graminifolia	ASTER	1	0.0004
Joycea pallida	PO	34	143
Juncus subgen. *Genuini*	JUNC	67	2.9
Leptorhynchos squamatus	ASTER	45	2.1
Lissanthe strigosa	EPACRID	11	6.9
Lomandra filiformis	LOMANDR	85	19.9
Lomandra multiflora	LOMANDR	13	0.63
Luzula spp.	JUNC	19	0.06
Lythrum hyssopifolia	LYTHR	4	0.02
Melichrus urceolatus	EPACRID	22	9.2
Mentha diemenica	LAMI	5	0.03
Microlaena stipoides	PO	65	7.0
Microseris lanceolata	ASTER	3	0.004
Opercularia hispida	RUBI	1	0.01
Oxalis perennans	OXALID	69	0.42
Panicum effusum	PO	52	2.5
Pimelea curviflora	THYMELAE	5	0.11
Pimelea linifolia	THYMELAE	1	0.01
Plantago gaudichaudii	PLANTAGIN	2	0.01
Plantago varia	PLANTAGIN	9	0.59
Poa sieberiana	PO	45	4.4
Pultenaea procumbens	FAB	1	0.07
Ranunculus sessiliflorus	RANUNCUL	5	0.14
Rumex brownii	POLYGON	26	0.31
Schoenus apogon	CYPER	8	0.13
Scleranthus biflorus	CAROPHYLL	3	0.01
Senecio hispidulus	ASTER	2	0.08
Senecio quadridentatus	ASTER	1	0.09
Solenogyne dominii	ASTER	75	1.8
Stackhousia monogyna	STACKHOUSI	4	0.11
Stuartina muelleri	ASTER	8	0.01
Stylidium graminifolium	STYLID	1	0.01
Thelymitra sp.	ORCHID	1	0.0005
Themeda australis	PO	79	50.6
Thysanotus patersonii	ANTHERIC	4	0.01
Tricoryne elatior	ANTHERIC	64	2.4
Triptilodiscus pygmaeus	ASTER	68	0.98
Viola betonicifolia	VIOL	4	0.05
Vittadinia cuneata	ASTER	4	0.03
Vittadinia muelleri	ASTER	32	2.1
Wahlenbergia spp.	CAMPANUL	55	0.50
Wurmbea dioica	COLCHIC	39	0.16

b) Exotic plant species

Acetosella vulgaris	POLYGON	26	0.85
Aira spp.	PO	92	0.79
Anagallis arvensis	PRIMUL	11	0.10
Aphanes arvensis	ROS	4	0.002
Arctotheca calendula	ASTER	45	3.5
Briza maxima	PO	17	0.21
Briza minor	PO	50	0.19
Bromus diandrus	PO	27	1.2
Bromus hordeaceus	PO	59	1.9
Bromus rubens	PO	6	0.19
Carduus pycnocephalus	ASTER	3	0.43
Carthamus lanatus	ASTER	3	0.26
Centaurium erythraea	GENTIAN	1	0.002
Chondrilla juncea	ASTER	9	0.39
Cicendia quadrangularis	GENTIAN	3	0.04
Echium plantagineum	BORAGIN	3	0.22
Erodium botrys	GERANI	5	0.03
Erodium cicutarium	GERANI	21	0.22
Galium divaricatum	RUBI	32	0.19
Galium murale	RUBI	1	0.001
Gamochaeta americana	ASTER	2	0.01
Gypsophila tubulosa	CAROPHYLL	3	0.02
Hordeum sp.	PO	5	0.60
Hypericum perforatum	CLUSI	1	0.04
Hypochaeris glabra	ASTER	72	2.1
Hypochaeris radicata	ASTER	58	2.4
Lactuca serriola	ASTER	2	0.09
Linaria arvensis	SCROPHULARI	2	0.01
Linaria pelisseriana	SCROPHULARI	7	0.03
Linum trigynum	LIN	2	0.001
Logfia gallica	ASTER	22	0.12
Lolium spp.	PO	53	10.2
Modiola caroliniana	MALV	1	0.04
Moenchia erecta	CAROPHYLL	15	0.02
Myosotis discolor	BORAGIN	6	0.05
Nassella trichotoma	PO	9	0.17
Paronychia brasiliana	CAROPHYLL	7	0.09
Paspalum dilatatum	PO	1	0.02
Petrorhagia nanteuilii	CAROPHYLL	31	0.14
Phalaris aquatica	PO	21	23.8
Plantago coronopus	PLANTAGIN	2	0.01
Plantago lanceolata	PLANTAGIN	2	0.003
Poa bulbosa	PO	39	1.8
Romulea rosea	IRID	1	0.005
Rosa rubiginosa	ROS	3	0.15
Salvia verbenaca	LAMI	3	0.22
Sherardia arvensis	RUBI	4	0.07
Silene gallica	CAROPHYLL	2	0.01
Sisymbrium officinale	BRASSIC	2	0.01
Soliva sessilis	ASTER	1	0.002
Tolpis barbata	ASTER	35	0.39
Trifolium angustifolium	FAB	5	0.33
Trifolium arvense	FAB	51	0.55
Trifolium campestre	FAB	8	0.02
Trifolium dubium	FAB	40	0.40
Trifolium glomeratum	FAB	40	1.3
Trifolium striatum	FAB	27	1.5
Trifolium subterraneum	FAB	80	10.5
Vulpia spp.	PO	88	1.1

Appendix 2. Floristic data and soil properties for 96 1 ha sites in Mulligans Flat (indicated by MF site codes) and Goorooyarroo Nature Reserves (indicated by WG and GO site codes). Floristic groups numbers are those described in Figure 3.

Site code	WG108-1	WG108-2	WG108-3	WG108-4	GO72A-1	GO72A-2	GO72A-3	GO72A-4	WG78-1	WG78-2	WG78-3	WG78-4	MF27A-1
Floristic group	1	1	1	1	2	2	3	3	2	2	4	2	2
a) Ground cover attributes													
Total biomass kgha^{-1}	1413	1452	779	509	418	688	877	1833	383	421	409	289	278
Live plant basal area %	3.3	10.0	8.3	10.0	8.3	4.2	12.5	13.3	9.2	5.8	9.2	12.5	12.5
Litter %	87.5	83.3	84.2	78.3	70.8	88.3	72.5	62.5	65.0	84.2	69.2	64.2	65.0
Litter depth where present (mm)	17.0	14.4	15.3	12.7	12.9	15.7	13.7	20.2	7.3	7.9	6.8	10.8	8.6
Bare ground %	5.0	5.0	5.0	5.0	15.0	3.3	9.2	9.2	15.8	3.3	12.5	12.5	7.5
Fallen log %	3.3	-	0.8	-	-	-	2.5	7.5	0.8	-	-	-	0.8
Cryptogam %	0.8	1.7	1.7	6.7	5.0	2.5	3.3	2.5	7.5	3.3	6.7	5.8	14.2
Rock %	-	-	-	-	0.8	1.7	-	5.0	1.7	3.3	2.5	5.0	-
b) Soil attributes (0 - 10 cm)													
Nitrate-N (mgkg^{-1})	9.8	5.8	9.3	6.1	0.4	0.6	0.5	0.5	0.7	0.9	0.3	1.5	1.7
Carbon (%)	2.8	2.3	3.4	3.0	1.9	2.1	2.5	3.4	2.2	2.8	2.3	2.4	2.0
Nitrogen (%)	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.1	0.1
Electrical conductivity (dSm^{-1})	0.1	0.1	0.1	0.1	<0.05	0.1	0.1	<0.05	<0.05	<0.05	<0.05	0.1	<0.05
pH(CaCl2)	4.6	4.3	4.4	4.3	4.5	4.7	4.5	4.3	5.0	5.0	4.9	4.8	4.4
pH(water)	5.3	5.0	5.1	5.0	5.3	5.4	5.3	5.2	5.8	5.8	5.7	5.5	5.2
Available phosphorous (mgkg^{-1})	11.0	9.0	11.0	13.0	4.0	5.0	6.0	8.0	5.0	7.0	7.0	7.0	<4
c) Native plant species (kg ha^{-1})													
Acacia dealbata	-	-	-	-	-	-	-	-	-	-	-	-	-
Acacia gunnii	-	-	-	-	-	-	-	-	-	-	-	-	-
Acacia parramattensis	-	-	-	-	-	6.07	-	-	-	-	-	-	-
Acaena ovina	-	-	-	-	0.88	5.06	-	-	1.53	0.06	1.94	2.82	-
Alternanthera sp. A	-	-	-	-	-	-	-	-	-	0.02	-	-	-
Aristida ramosa	-	-	-	-	198	95.54	151	58.05	-	-	-	22.53	4.85
Arthropodium minus	2.82	-	-	-	-	-	-	-	0.11	0.34	-	0.02	-
Asperula conferta	-	-	-	-	-	-	-	-	-	1.06	0.02	-	-
Astroloma humifusum	-	-	-	-	-	-	-	-	-	-	-	-	-
Austrodanthonia spp.	574	827	201	199	45.77	203	55.29	52.52	122	143	56.59	99.57	139
Austrostipa bigeniculata	77.61	71.35	174	0.07	-	72.78	-	-	-	-	-	29.98	-
Austrostipa densiflara	-	-	-	-	-	17.50	61.70	40.36	-	-	-	-	-
Austrostipa scabra	80.83	138	126	66.81	-	22.16	13.81	-	5.48	47.38	10.37	4.27	0.49
Bossiaea buxifolia	-	-	-	-	-	-	-	-	-	-	-	-	-
Bossiaea prostrata	-	-	-	-	-	-	-	-	-	-	-	-	-
Bothriochloa macra	-	-	18.20	27.72	-	2.03	9.71	1.71	110	85.41	87.93	38.48	6.14
Brachyloma daphnoides	-	-	-	-	-	-	-	-	-	-	-	-	-
Bulbine bulbosa	-	-	-	-	-	-	-	-	-	-	-	-	-
Carex inversa	-	1.93	0.54	-	-	0.55	-	-	-	-	-	0.05	-
Chamaesyce drummondii	-	-	-	-	-	-	-	-	-	-	0.17	-	-
Cheilanthes spp.	-	-	-	-	0.05	0.17	1.32	0.67	0.05	-	0.02	0.06	5.69
Chloris truncata	-	-	-	-	-	0.05	-	-	-	-	-	-	1.32
Chrysocephalum apiculatum	-	-	-	-	-	-	-	-	-	-	-	-	-
Chrysocephalum semipapposum	-	-	-	-	-	-	-	0.58	-	-	-	-	-
Convolvulus angustissimus	-	-	0.06	-	-	0.06	0.78	-	2.19	1.31	0.83	-	0.09
Cotula australis	-	-	-	-	-	-	-	-	-	-	-	0.13	-
Craspedia variabilis	-	-	-	-	-	-	-	-	-	-	-	-	-
Crassula sieberiana	2.61	8.97	1.27	0.33	-	0.08	-	0.06	-	0.22	0.06	0.18	0.06
Cymbonotus spp.	-	-	-	-	-	-	-	-	-	-	0.26	-	-
Cynodon dactylon	-	-	-	-	-	-	-	-	-	-	-	-	-
Cynoglossum suaveolens	-	0.79	-	-	-	-	-	-	0.18	0.92	0.70	-	-
Daucus glochidiatus	-	-	-	-	0.08	0.21	0.20	1.75	-	0.02	4.39	0.02	-
Daviesia genistifolia	-	-	-	-	-	0.03	-	-	-	-	-	-	-
Desmodium varians	4.37	1.25	0.09	0.42	-	1.53	1.05	0.78	3.74	1.42	1.28	0.51	-
Dianella revoluta	-	-	-	-	-	-	-	-	-	-	-	-	-
Dichelachne spp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Dichopogon fimbriatus	-	-	-	-	-	-	-	-	-	-	-	-	-
Dillwynia sericea	-	-	-	-	-	-	-	-	-	-	-	-	-
Diuris sulphurea	-	-	-	-	-	-	-	-	-	-	-	-	-
Drosera peltata	-	-	-	-	-	-	-	-	-	-	-	-	-
Einadia nutans	7.60	-	33.24	10.04	-	-	-	-	-	-	-	4.95	-
Eleocharis acuta	-	-	-	-	-	-	-	-	-	-	-	-	-
Elymus scaber	92.65	158	115	27.49	0.56	2.24	1.61	0.57	1.20	4.59	0.78	6.46	12.79
Enneapogon nigricans	-	-	-	-	-	-	0.96	-	-	-	-	-	-

Site code	WG108-1	WG108-2	WG108-3	WG108-4	GO72A-1	GO72A-2	GO72A-3	GO72A-4	WG78-1	WG78-2	WG78-3	WG78-4	MF27A-1
Eragrostis brownii	-	-	-	-	-	-	-	-	-	-	-	-	-
Erodium crinitum	-	-	-	-	-	-	-	-	-	-	-	-	-
Eryngium rostratum	-	-	-	-	-	-	-	-	-	-	-	-	-
Euchiton gymnocephalus	-	-	-	-	-	-	-	-	-	-	-	-	-
Euchiton sphaericus	-	-	-	-	-	-	-	-	-	-	-	-	-
Galium gaudichaudii	-	-	-	-	-	-	-	-	-	-	-	-	-
Geranium solanderi	-	-	-	-	0.06	-	0.35	0.08	0.01	-	-	0.47	-
Glycine spp.	-	-	-	-	0.02	2.65	-	-	0.69	2.82	0.19	0.17	-
Gonocarpus tetragynus	-	-	-	-	1.54	1.34	2.21	0.26	1.93	-	0.47	0.69	0.56
Goodenia hederacea	-	-	-	-	0.04	0.05	0.03	-	-	-	-	-	-
Goodenia pinnatifida	-	-	-	-	-	-	-	-	0.26	0.26	-	-	0.22
Haloragis heterophylla	-	-	-	-	-	-	-	-	-	-	0.05	-	-
Hibbertia obtusifolia	-	-	-	-	-	0.55	-	-	-	-	-	-	-
Hovea heterophylla	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydrocotyle laxiflora	-	-	0.46	-	0.71	2.30	4.17	0.78	6.85	2.25	0.14	1.73	3.58
Hypericum gramineum	-	-	-	-	-	0.18	0.02	0.09	0.06	1.22	0.66	-	-
Isoetopsis graminifolia	-	-	-	-	-	-	-	-	-	-	-	-	-
Joycea pallida	-	-	-	-	-	-	379	1454	-	-	-	-	-
Juncus subgen. *Genuini*	14.90	-	-	0.58	1.85	-	-	-	-	0.43	-	-	-
Leptorhynchos squamatus	-	-	-	-	15.05	5.88	1.43	0.77	6.58	0.67	9.36	4.60	-
Lissanthe strigosa	-	-	-	-	25.55	5.69	-	-	-	-	-	-	-
Lomandra filifarmis	-	10.14	1.60	3.19	58.61	172.09	151.38	26.88	-	2.37	-	9.63	36.12
Lomandra multiflora	-	-	-	-	-	-	-	-	-	-	-	-	-
Luzula spp.	-	-	-	-	0.34	-	0.02	-	-	-	0.04	-	-
Lythrum hyssopifolia	-	-	-	-	-	-	-	-	-	-	-	-	-
Melichrus urceolatus	-	-	-	-	0.40	41.81	-	134.33	10.37	-	-	-	-
Mentha diemenica	-	-	-	-	-	-	-	-	-	-	0.06	-	-
Microlaena stipoides	2.93	22.04	-	62.23	-	2.09	0.66	-	-	0.21	1.73	-	0.06
Microseris lanceolata	-	-	-	-	0.04	-	-	-	-	-	0.30	-	-
Opercularia hispida	-	-	-	-	-	-	-	-	-	-	-	-	-
Oxalis perennans	7.59	0.63	1.21	1.34	0.04	-	-	2.59	0.03	0.15	0.26	0.16	0.33
Panicum effusum	-	-	-	-	-	-	-	-	-	-	-	-	2.16
Pimelea curviflora	-	-	-	-	-	-	-	-	-	-	-	-	-
Pimelea linifolia	-	-	-	-	-	-	-	-	-	-	-	-	-
Plantaga gaudichaudii	-	-	-	-	-	-	-	-	-	-	-	-	-
Plantago varia	-	-	-	-	-	-	0.60	-	4.44	2.22	-	-	-
Poa sieberiana	-	-	-	-	-	-	-	-	-	-	5.59	-	-
Pultenaea procumbens	-	-	-	-	-	-	-	-	-	-	-	-	-
Ranunculus sessiliflorus	-	-	-	-	-	-	-	-	-	-	-	-	-
Rumex brownii	0.36	0.82	-	-	-	-	-	-	-	4.07	0.68	-	-
Schoenus apogon	-	-	-	-	2.25	2.94	3.10	-	-	-	-	-	-
Scleranthus biflorus	-	-	-	-	-	-	-	-	-	-	-	-	-
Senecio hispidulus	-	-	-	-	-	-	-	-	-	-	-	-	-
Senecio quadridentatus	-	-	-	-	-	-	-	-	-	-	-	-	-
Solenogyne dominii	0.06	-	-	0.02	1.06	0.21	-	0.07	3.42	0.15	0.80	0.84	2.02
Stackhousia monogyna	-	-	-	-	-	-	-	0.17	-	-	-	-	-
Stuartina muelleri	-	0.06	-	0.24	-	-	-	-	-	-	-	-	-
Stylidium graminifolium	-	-	-	-	-	-	-	-	-	-	-	-	-
Thelymitra sp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Themeda australis	-	-	-	-	58.31	2.08	27.29	15.81	82.38	22.73	198	32.05	-
Thysanotus patersonii	-	-	-	-	0.04	0.19	-	0.23	-	-	-	-	-
Tricoryne elatiar	-	0.53	0.11	0.62	4.70	2.94	0.05	0.62	-	-	-	-	0.05
Triptilodiscus pygmaeus	-	0.17	-	-	0.11	0.06	0.31	1.04	1.30	0.25	0.63	1.38	0.63
Viola betonicifolia	-	-	-	-	-	-	-	-	-	-	-	-	-
Vittadinia cuneata	-	-	-	-	-	-	-	-	-	-	-	-	-
Vittadinia muelleri	-	-	-	-	-	0.20	-	-	9.63	-	10.93	-	1.93
Wahlenbergia spp.	-	-	-	-	-	4.62	0.60	2.54	3.39	0.17	0.81	0.31	1.31
Wurmbea dioica	-	-	-	-	1.23	0.05	1.77	0.02	0.07	0.02	1.11	0.72	-
d) Exotic plant species (kg ha^{-1})													
Acetosella vulgaris	-	-	-	-	-	-	-	-	-	-	-	-	0.21
Aira spp.	-	0.40	-	0.50	0.22	0.40	0.14	0.37	1.19	0.03	0.15	0.91	4.50
Anagallis arvensis	-	-	-	-	-	-	-	-	-	-	-	-	-
Aphanes arvensis	-	-	-	-	-	-	-	-	-	-	-	-	-
Arctotheca calendula	24.58	8.58	10.84	4.31	-	-	-	-	0.28	38.27	0.07	1.32	8.57
Briza maxima	-	-	-	-	-	-	-	-	-	-	-	-	-
Briza minor	-	-	-	-	-	-	-	-	-	-	0.13	-	-
Bromus diandrus	3.07	-	0.43	1.69	-	-	-	-	-	-	-	-	0.38
Bromus hordeaceus	-	33.06	-	0.11	-	-	0.09	-	0.12	1.32	0.42	-	-
Bromus rubens	-	-	-	-	-	-	-	-	-	-	-	-	-
Carduus pycnocephalus	-	-	-	-	-	-	-	-	-	-	-	-	-
Carthamus lanatus	-	5.59	-	-	-	-	-	-	-	-	-	-	-

Site code	WG108-1	WG108-2	WG108-3	WG108-4	GO72A-1	GO72A-2	GO72A-3	GO72A-4	WG78-1	WG78-2	WG78-3	WG78-4	MF27A-1
Centaurium erythraea	-	-	-	-	-	-	-	-	-	-	-	-	-
Chondrilla juncea	-	-	-	-	-	-	-	-	-	-	-	-	-
Cicendia quadrangularis	-	-	-	-	-	-	-	-	-	-	0.08	-	-
Echium plantagineum	-	-	-	-	-	-	-	-	-	-	-	-	-
Erodium botrys	-	-	-	-	-	-	-	-	-	-	-	-	-
Erodium cicutarium	0.92	-	-	-	-	4.63	-	-	-	0.06	-	0.17	-
Galium divaricatum	-	-	-	-	0.03	-	-	-	-	-	-	-	-
Galium murale	-	-	-	-	-	-	-	-	-	-	-	-	-
Gamochaeta americana	-	-	-	-	-	-	-	-	-	-	-	-	-
Gypsophila tubulosa	-	-	-	-	-	-	-	-	-	-	-	-	-
Hordeum sp.	-	-	4.82	5.69	-	-	-	-	-	-	-	-	-
Hypericum perforatum	-	-	-	-	-	-	-	-	-	-	-	-	-
Hypochaeris glabra	-	0.53	-	-	-	-	0.14	0.51	0.45	1.09	-	0.20	-
Hypochaeris radicata	11.04	13.54	2.18	-	-	-	-	-	-	3.66	0.07	0.17	4.42
Lactuca serriola	-	-	-	-	-	-	-	-	-	-	-	-	-
Linaria arvensis	-	-	-	-	-	-	-	-	-	-	-	-	-
Linaria pelisseriana	-	-	-	-	-	-	-	-	-	-	-	-	-
Linum trigynum	-	-	-	-	-	-	-	-	-	-	-	-	-
Logfia gallica	-	-	-	-	-	-	-	-	-	-	-	-	-
Lolium spp.	196	69.38	50.93	80.10	-	-	-	-	-	0.04	0.17	1.48	1.26
Modiola caroliniana	-	-	-	-	-	-	-	-	-	-	-	-	-
Moenchia erecta	0.16	-	-	-	-	-	-	-	-	-	-	-	-
Myosotis discolor	-	-	-	-	-	-	-	-	-	-	-	-	-
Nassella trichotoma	-	-	-	-	-	0.56	-	3.30	-	-	-	-	-
Paronychia brasiliana	0.08	-	4.45	-	-	-	-	-	-	1.26	-	-	-
Paspalum dilatatum	-	-	2.25	-	-	-	-	-	-	-	-	-	-
Petrorhagia nanteuilii	-	-	-	-	-	-	-	-	-	0.07	-	0.02	-
Phalaris aquatica	234	27.53	-	7.91	-	-	-	-	-	-	-	-	-
Plantago coronopus	-	-	-	-	-	-	-	-	-	-	-	-	-
Plantago lanceolata	-	-	-	-	-	-	-	-	-	-	-	-	-
Poa bulbosa	-	3.35	1.75	3.48	-	-	-	-	2.51	30.62	-	20.29	5.12
Romulea rosea	-	-	-	-	-	-	-	-	-	-	-	-	-
Rosa rubiginosa	-	-	-	-	-	-	-	3.00	-	-	-	-	-
Salvia verbenaca	-	-	-	-	-	-	-	-	-	-	-	-	-
Sherardia arvensis	-	-	-	-	-	-	-	-	-	-	-	-	-
Silene gallica	-	-	-	-	-	-	-	-	-	-	-	-	-
Sisymbrium officinale	-	-	-	-	-	-	-	-	-	-	-	-	-
Soliva sessilis	-	-	-	-	-	-	-	-	-	-	-	-	-
Tolpis barbata	-	-	-	-	-	-	-	-	-	-	-	-	0.29
Trifolium angustifolium	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifolium arvense	-	-	-	-	-	-	-	-	0.43	3.95	7.72	0.51	0.75
Trifolium campestre	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifolium dubium	-	-	-	0.06	-	-	-	-	0.07	-	2.15	-	0.04
Trifolium glomeratum	-	-	-	-	-	-	-	-	-	-	0.08	0.47	0.24
Trifolium striatum	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifolium subterraneum	57.48	14.80	19.42	0.26	-	0.17	2.00	-	-	14.83	0.05	0.02	29.69
Vulpia spp.	4.98	3.43	3.26	0.71	0.12	0.51	0.03	0.22	-	0.19	0.80	0.03	0.06

Site code	MF27A-2	MF27A-3	MF27A-4	MF34-1	MF34-2	MF34-3	MF34-4	MF16A-1	MF16A-2	MF16A-3	MF16A-4	WG92-1	WG92-2
Floristic group	5	2	2	4	4	2	1	2	4	2	2	6	6
a) Ground cover attributes													
Total biomass kgha^{-1}	378	277	266	211	213	219	674	314	356	315	276	421	472
Live plant basal area %	13.3	13.3	11.7	2.5	5.8	6.7	15.8	21.7	25.8	8.3	19.2	24.2	20.8
Litter %	45.0	51.7	52.5	82.5	74.2	73.3	74.2	70.0	55.8	66.7	54.2	56.7	69.2
Litter depth where present (mm)	7.9	12.6	6.3	16.9	15.7	20.4	22.5	7.7	9.6	20.9	14.3	11.5	12.0
Bare ground %	25.0	27.5	23.3	12.5	17.5	12.5	2.5	5.0	15.0	16.7	15.0	7.5	2.5
Fallen log %	0.8	-	0.8	1.7	-	6.7	7.5	-	-	4.2	-	-	-
Cryptogam %	15.0	7.5	10.8	0.8	2.5	0.8	-	3.3	3.3	4.2	11.7	11.7	7.5
Rock %	0.8	-	0.8	-	-	-	-	-	-	-	-	-	-
b) Soil attributes (0 - 10 cm)													
Nitrate-N (mgkg^{-1})	0.8	2.4	1.4	0.5	0.5	1.5	3.2	0.7	1.0	1.1	1.3	4.8	5.9
Carbon (%)	1.5	1.8	1.8	3.8	2.7	3.4	3.3	3.1	3.4	3.4	3.0	2.5	2.5
Nitrogen (%)	0.1	0.1	0.1	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Site code	MF27A-2	MF27A-3	MF27A-4	MF34-1	MF34-2	MF34-3	MF34-4	MF16A-1	MF16A-2	MF16A-3	MF16A-4	WG92-1	WG92-2
Electrical conductivity (dSm^{-1})	<0.05	0.1	<0.05	0.1	0.1	0.1	0.1	<0.05	<0.05	0.1	<0.05	0.1	<0.05
pH(CaCl2)	4.4	4.4	4.4	4.5	4.6	4.4	4.7	4.5	4.5	4.3	4.5	4.7	4.5
pH(water)	5.4	5.1	5.3	5.3	5.4	5.1	5.5	5.3	5.4	5.0	5.3	5.5	5.3
Available phosphorous ($mgkg^{-1}$)	<4	4.0	<4	7.0	7.0	10.0	13.0	10.0	9.0	9.0	8.0	9.0	8.0
c) Native plant species (kg ha^{-1})													
Acacia dealbata	-	-	-	-	-	-	-	-	-	-	-	-	-
Acacia gunnii	-	-	-	-	-	-	-	-	-	-	-	-	-
Acacia parramattensis	-	-	-	-	-	-	-	-	-	-	-	-	-
Acaena ovina	0.02	14.88	5.19	-	-	0.43	-	8.97	1.17	6.72	18.95	0.48	0.13
Alternanthera sp. *A*	-	-	-	-	-	-	-	-	-	-	-	-	-
Aristida ramosa	29.19	6.48	14.03	-	-	-	-	11.70	0.35	8.36	25.90	-	-
Arthropodium minus	-	0.05	0.31	0.41	0.84	-	2.24	-	-	-	3.01	-	-
Asperula conferta	-	0.22	-	-	-	-	0.06	0.16	2.03	1.98	8.11	0.13	0.23
Astroloma humifusum	-	-	-	-	-	-	-	-	-	-	-	-	-
Austrodanthonia spp.	146	119	156	67.89	58.48	94.37	80.67	89.30	65.96	105	92.63	49.73	62.18
Austrostipa bigeniculata	-	-	-	-	-	-	-	-	-	-	-	50.96	27.05
Austrostipa densiflora	-	-	-	-	-	-	-	-	-	-	-	-	-
Austrostipa scabra	2.10	8.92	4.99	-	4.70	-	-	0.02	-	1.26	-	14.08	-
Bossiaea buxifolia	-	-	-	-	-	-	-	-	-	-	-	-	-
Bossiaea prostrata	-	-	-	0.53	-	-	-	-	-	-	-	-	-
Bothriochloa macra	-	8.42	10.91	-	-	-	-	47.26	22.48	0.02	11.00	21.73	57.49
Brachyloma daphnoides	-	-	-	-	-	-	-	-	-	-	-	-	-
Bulbine bulbosa	-	-	-	10.63	3.05	-	-	-	-	-	-	-	-
Carex inversa	-	-	-	-	-	-	0.11	-	-	0.56	-	-	-
Chamaesyce drummondii	-	-	-	-	-	-	-	-	-	-	-	-	-
Cheilanthes spp.	0.05	-	0.02	-	-	-	-	-	-	-	-	-	-
Chloris truncata	2.97	0.60	-	-	-	-	-	-	-	-	-	-	1.93
Chrysocephalum apiculatum	-	-	-	-	-	-	-	-	-	-	-	-	-
Chrysocephalum semipapposum	-	-	-	-	-	-	-	-	-	-	-	-	-
Convolvulus angustissimus	-	-	-	-	-	-	-	-	-	-	-	-	-
Cotula australis	-	-	-	-	-	-	-	-	-	-	-	-	-
Craspedia variabilis	-	-	-	0.86	2.59	3.15	0.04	1.41	-	-	0.62	-	-
Crassula sieberiana	0.06	0.02	0.08	-	0.01	-	0.01	-	-	0.22	0.90	-	0.11
Cymbonotus spp.	0.16	-	-	-	-	-	-	0.06	-	-	0.21	-	-
Cynodon dactylon	-	-	-	-	-	-	-	-	-	-	-	-	-
Cynoglossum suaveolens	-	-	-	-	-	-	-	-	-	-	-	-	-
Daucus glochidiatus	-	0.06	-	0.07	0.36	-	-	-	-	1.65	0.16	-	-
Daviesia genistifolia	-	12.36	-	-	-	-	-	-	-	-	-	-	-
Desmodium varians	-	0.18	-	-	-	-	-	-	-	-	-	-	-
Dianella revoluta	-	-	-	-	-	-	-	-	-	-	-	-	-
Dichelachne spp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Dichopogon fimbriatus	-	-	-	-	-	-	-	-	-	-	-	-	-
Dillwynia sericea	-	-	-	-	-	-	-	-	-	-	-	-	-
Diuris sulphurea	-	-	-	-	-	-	-	-	-	-	-	-	-
Drosera peltata	-	-	-	-	-	-	-	-	-	-	-	-	-
Einadia nutans	-	-	-	-	-	-	-	-	-	-	-	-	-
Eleocharis acuta	-	-	-	-	-	-	-	-	-	-	-	-	-
Elymus scaber	0.93	13.61	13.33	0.43	-	2.75	6.78	5.41	8.69	7.80	4.73	11.17	52.23
Enneapogon nigricans	-	-	0.05	-	-	-	-	-	-	-	-	-	-
Eragrostis brownii	-	-	-	-	-	-	-	-	-	-	-	-	-
Erodium crinitum	-	-	-	-	-	-	-	-	-	-	-	-	-
Eryngium rostratum	1.78	-	-	-	-	-	-	-	-	-	-	-	-
Euchiton gymnocephalus	-	-	-	-	-	-	-	-	-	-	-	-	-
Euchiton sphaericus	-	-	-	-	-	-	-	-	-	-	-	-	-
Galium gaudichaudii	-	-	-	-	-	-	-	-	-	-	-	-	-
Geranium solanderi	-	0.07	-	0.37	-	4.48	0.54	-	-	0.53	0.04	-	0.05
Glycine spp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Gonocarpus tetragynus	3.16	0.53	1.61	2.78	1.19	2.95	-	1.85	-	9.75	3.31	-	-
Goodenia hederacea	0.75	-	-	-	0.01	0.37	-	-	-	0.98	-	-	-
Goodenia pinnatifida	-	-	-	-	-	-	-	-	-	-	-	-	8.65
Haloragis heterophylla	0.53	0.21	0.05	0.07	0.02	-	-	0.04	0.08	0.02	0.23	-	-
Hibbertia obtusifolia	-	-	-	-	-	-	-	-	-	0.33	-	-	-
Hovea heterophylla	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydrocotyle laxiflora	-	-	-	8.34	2.71	7.04	0.07	-	0.51	4.35	5.79	-	-
Hypericum gramineum	-	0.67	-	0.13	0.38	0.21	0.03	-	-	-	-	-	0.10
Isoetopsis graminifolia	-	-	-	-	-	-	-	-	-	-	-	-	-
Joycea pallida	110	-	-	-	-	-	-	-	-	61.34	-	-	-
Juncus subgen. *Genuini*	-	-	0.67	12.09	11.38	0.09	1.52	12.42	19.52	3.26	1.11	-	4.59
Leptorhynchos squamatus	10.67	0.49	3.41	15.67	4.01	1.08	-	-	-	-	-	-	-

Site code	MF27A-2	MF27A-3	MF27A-4	MF34-1	MF34-2	MF34-3	MF34-4	MF16A-1	MF16A-2	MF16A-3	MF16A-4	WG92-1	WG92-2
Lissanthe strigosa	-	-	-	-	-	-	-	-	-	-	-	-	-
Lomandra filiformis	9.76	0.60	7.93	10.78	8.52	20.61	-	-	9.64	27.02	0.42	12.84	40.26
Lomandra multiflora	-	-	-	-	2.17	-	-	-	-	-	-	-	-
Luzula spp.	-	-	0.02	-	-	-	-	0.02	0.25	0.77	-	-	-
Lythrum hyssopifolia	-	-	-	-	-	-	-	-	-	-	-	-	-
Melichrus urceolatus	0.05	8.65	-	-	-	-	-	-	-	-	-	-	-
Mentha diemenica	-	-	-	-	-	-	-	-	-	-	-	-	-
Microlaena stipoides	-	0.05	-	-	-	17.65	34.23	30.84	32.76	4.65	21.39	-	-
Microseris lanceolata	-	-	-	-	-	-	-	-	-	-	-	-	-
Opercularia hispida	-	-	-	-	-	-	-	-	-	-	-	-	-
Oxalis perennans	0.02	0.19	-	1.28	0.07	1.11	-	0.26	0.44	0.82	1.39	0.80	0.02
Panicum effusum	9.75	2.40	1.92	-	-	-	0.09	0.71	-	-	-	-	0.02
Pimelea curviflora	-	-	-	-	-	-	-	-	-	-	-	-	-
Pimelea linifolia	-	-	-	-	-	-	-	-	-	-	-	-	-
Plantago gaudichaudii	-	-	-	-	-	-	-	-	-	-	-	-	-
Plantago varia	-	-	-	-	-	0.05	0.47	-	-	-	-	-	-
Poa sieberiana	-	-	-	-	7.24	1.20	-	-	-	-	-	-	-
Pultenaea procumbens	-	-	-	-	-	-	-	-	-	-	-	-	-
Ranunculus sessiliflorus	-	-	-	0.04	0.03	2.37	7.83	-	-	-	3.00	-	-
Rumex brownii	-	-	-	-	0.19	0.30	0.02	-	0.25	-	-	0.16	0.87
Schoenus apogon	-	-	-	1.93	-	-	-	-	-	-	-	-	-
Scleranthus biflorus	-	-	-	-	-	-	-	-	-	0.02	-	-	-
Senecio hispidulus	-	-	-	-	-	-	-	-	-	-	-	-	-
Senecio quadridentatus	-	-	-	-	-	-	-	-	-	-	-	-	-
Solenogyne dominii	0.45	-	0.15	1.92	0.24	0.59	-	5.46	2.69	6.62	3.53	-	-
Stackhousia monogyna	-	-	-	-	-	-	-	-	-	-	-	-	-
Stuartina muelleri	0.03	-	-	-	-	-	-	0.10	-	-	0.01	-	-
Stylidium graminifolium	-	-	-	-	-	-	-	-	-	-	-	-	-
Thelymitra sp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Themeda australis	0.75	10.28	-	61.57	82.73	10.10	-	60.99	173.97	25.70	49.29	38.03	36.56
Thysanotus patersonii	-	-	-	-	-	-	-	-	-	-	-	-	-
Tricoryne elatior	11.13	0.78	0.31	2.12	-	1.46	-	0.17	1.24	-	0.21	-	2.57
Triptilodiscus pygmaeus	3.45	1.20	8.58	0.47	0.08	-	-	2.35	0.54	3.69	3.21	-	-
Viola betonicifolia	-	-	-	-	-	-	0.58	-	-	-	-	-	-
Vittadinia cuneata	-	-	-	-	-	-	-	0.62	-	-	-	-	-
Vittadinia muelleri	10.60	6.67	1.31	-	-	-	-	27.57	6.75	5.34	8.76	-	-
Wahlenbergia spp.	0.59	-	-	-	0.90	0.21	-	-	-	-	0.02	0.19	-
Wurmbea dioica	0.05	0.05	0.85	-	0.16	-	-	1.48	0.75	0.17	2.71	-	-
d) Exotic plant species (kg ha^{-1})													
Acetosella vulgaris	-	8.91	-	-	-	-	3.05	0.21	0.71	-	-	-	-
Aira spp.	1.26	1.78	0.97	4.70	0.14	0.85	0.05	0.17	0.76	1.29	1.67	0.76	0.41
Anagallis arvensis	-	-	-	-	-	-	-	-	-	-	-	-	-
Aphanes arvensis	-	-	-	-	-	-	0.06	0.09	-	-	-	-	0.06
Arctotheca calendula	-	6.73	-	-	-	-	-	-	-	0.08	-	5.69	33.26
Briza maxima	-	-	-	-	-	0.09	-	-	-	-	-	-	-
Briza minor	0.02	-	-	0.06	0.03	0.02	-	0.18	0.05	0.18	1.13	-	-
Bromus diandrus	-	1.89	-	-	-	-	0.74	-	-	-	-	0.02	-
Bromus hordeaceus	-	0.45	-	0.26	1.63	4.64	3.06	-	-	0.48	0.10	8.39	32.91
Bromus rubens	-	-	-	-	-	-	-	-	-	-	-	-	-
Carduus pycnocephalus	-	-	-	2.45	-	-	-	-	-	-	-	-	-
Carthamus lanatus	-	-	-	-	-	-	-	-	-	-	-	-	-
Centaurium erythraea	-	-	-	-	-	-	-	-	-	-	0.20	-	-
Chondrilla juncea	-	-	-	-	-	-	-	-	-	-	-	-	-
Cicendia quadrangularis	-	-	-	-	-	-	-	-	-	-	-	-	-
Echium plantagineum	-	8.16	-	-	-	-	-	-	-	-	-	-	12.22
Erodium botrys	-	-	-	-	-	-	-	-	-	-	-	-	-
Erodium cicutarium	-	-	-	-	-	-	-	-	-	-	-	7.73	1.29
Galium divaricatum	-	-	-	0.01	-	0.15	0.11	-	-	-	-	-	-
Galium murale	-	-	-	-	-	-	-	-	-	-	-	-	-
Gamochaeta americana	-	-	-	-	-	-	-	0.24	-	-	0.67	-	-
Gypsophila tubulosa	-	-	-	-	-	-	-	-	-	-	-	-	-
Hordeum sp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hypericum perforatum	-	-	-	-	-	-	-	-	-	-	-	-	-
Hypochaeris glabra	0.36	-	-	0.04	-	-	-	-	-	0.12	0.06	-	0.11
Hypochaeris radicata	6.00	2.29	21.59	0.02	-	2.54	2.49	0.81	0.31	0.37	0.14	0.62	4.35
Lactuca serriola	-	-	-	-	-	-	-	-	-	-	-	-	-
Linaria arvensis	-	-	-	-	-	-	-	-	-	-	-	-	-
Linaria pelisseriana	-	-	-	-	-	-	-	-	-	-	-	-	-
Linum trigynum	-	-	-	-	-	-	-	-	-	-	-	-	-

Site code	MF27A-2	MF27A-3	MF27A-4	MF34-1	MF34-2	MF34-3	MF34-4	MF16A-1	MF16A-2	MF16A-3	MF16A-4	WG92-1	WG92-2
Logfia gallica	-	0.17	-	-	-	-	-	-	-	-	-	-	-
Lolium spp.	-	1.09	-	0.18	9.29	13.47	50.28	-	-	0.71	0.37	65.60	13.89
Modiola caroliniana	-	-	-	-	-	-	-	-	-	-	-	3.70	-
Moenchia erecta	0.49	0.06	0.05	-	-	-	-	-	-	-	-	0.14	0.07
Myosotis discolor	-	-	-	-	-	3.50	0.25	-	-	0.17	-	-	-
Nassella trichotoma	-	-	-	-	-	-	-	0.06	-	-	-	-	-
Paronychia brasiliana	-	-	-	-	-	-	-	-	-	-	-	-	-
Paspalum dilatatum	-	-	-	-	-	-	-	-	-	-	-	-	-
Petrorhagia nanteuilii	-	-	-	0.26	-	-	-	-	-	-	-	-	-
Phalaris aquatica	-	-	-	-	-	6.59	473	-	-	-	-	-	-
Plantago coronopus	-	-	-	-	-	-	-	-	-	-	-	-	-
Plantago lanceolata	-	-	-	-	-	-	-	-	-	-	-	-	0.20
Poa bulbosa	-	2.40	0.56	-	0.17	6.64	0.46	-	-	-	-	42.06	1.76
Romulea rosea	-	-	-	-	-	-	-	-	-	-	-	-	-
Rosa rubiginosa	-	-	-	-	-	-	-	-	-	-	-	-	-
Salvia verbenaca	-	-	-	-	-	-	-	-	-	-	-	-	-
Sherardia arvensis	-	-	-	-	-	-	-	-	-	-	-	-	-
Silene gallica	-	-	-	-	-	-	-	-	-	-	-	-	-
Sisymbrium officinale	-	-	-	-	-	-	-	-	-	-	-	1.11	-
Soliva sessilis	-	-	-	-	-	0.21	-	-	-	-	-	-	-
Tolpis barbata	0.05	0.22	0.24	-	-	-	-	-	-	-	-	-	-
Trifolium angustifolium	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifolium arvense	0.17	0.17	0.12	-	-	-	-	0.02	-	-	0.03	0.05	-
Trifolium campestre	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifolium dubium	-	0.02	0.06	0.13	0.04	0.27	0.27	0.48	0.15	0.07	0.11	-	0.17
Trifolium glomeratum	-	1.56	0.66	-	-	-	-	-	-	0.03	0.06	15.22	2.76
Trifolium striatum	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifolium subterraneum	14.70	22.54	9.26	1.41	0.26	4.09	0.67	3.05	3.38	6.79	0.82	67.92	72.60
Vulpia spp.	0.05	0.17	0.17	0.14	0.46	-	-	-	0.04	10.40	-	0.05	0.50
Vulpia spp.	0.05	0.17	0.17	0.14	0.46	-	-	-	0.04	10.40	-	0.05	0.50

Site code	WG92-3	WG92-4	MF22A-1	MF22A-2	MF22A-3	MF22A-4	MF19A-1	MF19A-2	MF19A-3	MF19A-4	WG81-1	WG81-2	WG81-3
Floristic group	6	6	3	3	3	3	4	4	4	2	2	2	2
a) Ground cover attributes													
Total biomass kgha^{-1}	334	306	2352	1241	1722	890	229	232	304	288	355	398	363
Live plant basal area %	34.2	15.8	14.2	10.0	18.3	12.5	7.5	6.7	7.5	1.7	10.8	13.3	11.7
Litter %	55.8	66.7	60.8	69.2	54.2	68.3	85.8	87.5	79.2	85.0	74.2	74.2	63.3
Litter depth where present (mm)	6.6	14.5	16.5	11.6	12.4	13.1	15.7	24.1	20.5	20.2	13.1	11.9	11.6
Bare ground %	5.8	3.3	17.5	10.8	21.7	14.2	5.8	2.5	9.2	9.2	13.3	6.7	15.0
Fallen log %	-	5.0	-	-	-	0.8	-	3.3	2.5	0.8	-	1.7	-
Cryptogam %	4.2	2.5	7.5	9.2	5.8	4.2	0.8	-	1.7	3.3	1.7	4.2	8.3
Rock %	-	6.7	-	0.8	-	-	-	-	-	-	-	-	1.7
b) Soil attributes (0 - 10 cm)													
Nitrate-N (mgkg^{-1})	3.3	8.0	1.6	<0.25	2.8	<0.25	0.4	1.2	0.4	1.2	1.0	0.5	0.3
Carbon (%)	2.7	3.3	2.2	2.8	2.3	2.2	3.6	3.5	3.3	2.9	2.7	2.6	2.4
Nitrogen (%)	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1
Electrical conductivity (dSm^{-1})	0.1	0.1	<0.05	<0.05	<0.05	<0.05	0.1	0.1	0.1	<0.05	<0.05	<0.05	<0.05
pH(CaCl2)	4.7	5.2	4.1	4.0	4.1	4.1	4.4	4.4	4.3	4.4	4.4	4.5	4.2
pH(water)	5.5	5.8	4.9	4.8	4.9	4.9	5.1	5.2	5.0	5.2	5.2	5.4	5.1
Available phosphorous (mgkg^{-1})	7.0	9.0	7.0	6.0	6.0	6.0	10.0	12.0	11.0	5.0	8.0	<4	<4
c) Native plant species (kg ha^{-1})													
Acacia dealbata	-	-	-	-	-	-	-	-	-	-	-	-	-
Acacia gunnii	-	-	-	-	-	-	-	-	-	-	-	-	-
Acacia parramattensis	-	-	-	-	-	-	-	-	-	-	-	-	-
Acaena ovina	24.03	0.77	-	-	0.05	-	-	-	-	-	-	-	-
Alternanthera sp. A	-	-	-	-	-	-	-	-	-	-	-	-	-
Aristida ramosa	-	8.65	72.96	46.25	112.23	123.26	-	-	14.12	0.77	115	113	104
Arthropodium minus	-	-	-	-	-	-	-	0.04	-	0.53	-	-	-
Asperula conferta	-	-	-	-	0.22	-	-	-	0.05	-	-	-	-
Astroloma humifusum	-	-	-	-	-	-	-	-	-	-	-	-	-
Austrodanthonia spp.	56.15	54.10	18.94	25.18	50.98	35.92	26.29	7.72	11.80	74.57	61.32	35.11	71.23

Site code	WG92-3	WG92-4	MF22A-1	MF22A-2	MF22A-3	MF22A-4	MF19A-1	MF19A-2	MF19A-3	MF19A-4	WG81-1	WG81-2	WG81-3
Austrostipa bigeniculata	-	6.18	-	-	-	-	-	-	-	-	-	-	-
Austrostipa densiflora	-	-	-	-	-	-	-	-	-	-	22.82	48.39	79.46
Austrostipa scabra	0.17	2.59	-	-	-	-	-	-	-	-	5.14	-	2.23
Bossiaea buxifolia	-	-	-	-	-	-	-	2.22	-	-	-	-	-
Bossiaea prostrata	-	-	-	-	-	-	-	0.02	-	0.45	-	-	-
Bothriochloa macra	42.58	49.28	-	-	0.62	-	-	-	0.51	-	7.47	4.90	0.48
Brachyloma daphnoides	-	-	85.14	-	-	-	-	-	-	-	-	-	-
Bulbine bulbosa	-	-	-	-	-	-	-	-	-	-	-	-	-
Carex inversa	-	0.06	-	-	-	-	-	-	-	-	1.03	-	-
Chamaesyce drummondii	0.25	-	-	-	-	-	-	-	-	-	-	-	-
Cheilanthes spp.	-	-	1.59	0.03	1.29	-	-	-	-	-	0.02	1.23	0.67
Chloris truncata	-	-	-	-	3.19	5.17	-	-	-	-	-	-	-
Chrysocephalum apiculatum	-	-	-	-	-	0.19	-	-	-	-	-	10.13	-
Chrysocephalum semipapposum	-	-	-	-	-	-	-	-	-	-	-	-	-
Convolvulus angustissimus	-	-	-	-	-	-	-	-	-	-	-	-	-
Cotula australis	-	-	-	-	-	-	-	-	-	-	-	-	-
Craspedia variabilis	-	-	-	-	-	-	-	-	-	-	-	3.37	-
Crassula sieberiana	-	0.05	-	0.05	-	-	-	-	-	-	0.28	0.03	-
Cymbonotus spp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Cynodon dactylon	-	-	-	-	-	-	-	-	-	-	0.02	-	-
Cynoglossum suaveolens	-	-	-	-	-	-	-	-	-	-	-	-	-
Daucus glochidiatus	-	-	-	-	-	-	0.12	0.45	0.27	0.65	-	0.02	0.53
Daviesia genistifolia	-	-	-	-	-	-	-	-	-	4.59	-	-	-
Desmodium varians	-	0.35	-	-	-	-	-	-	-	-	0.47	0.23	1.35
Dianella revoluta	-	-	-	-	-	-	-	-	-	-	-	-	-
Dichelachne spp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Dichopogon fimbriatus	-	-	-	-	-	-	-	-	-	-	-	-	-
Dillwynia sericea	-	-	1.17	-	-	-	-	-	-	-	-	-	-
Diuris sulphurea	-	-	11.77	-	0.03	-	-	-	-	-	-	-	-
Drosera peltata	-	-	-	0.14	0.36	-	-	-	-	-	-	-	-
Einadia nutans	-	-	-	-	-	-	-	-	-	-	-	-	-
Eleocharis acuta	-	-	-	-	-	-	-	0.71	-	-	-	-	-
Elymus scaber	6.74	42.46	-	-	-	-	1.82	16.62	0.12	0.13	6.12	0.63	2.56
Enneapogon nigricans	-	-	-	-	-	-	-	-	-	-	-	-	-
Eragrostis brownii	-	-	0.63	-	-	-	-	2.37	-	-	-	0.03	-
Erodium crinitum	-	-	-	-	-	-	-	-	-	-	-	-	-
Eryngium rostratum	-	-	-	-	-	-	-	-	-	-	-	-	-
Euchiton gymnocephalus	-	-	-	-	-	-	-	-	-	-	-	-	-
Euchiton sphaericus	-	-	-	-	-	-	-	-	-	-	-	-	-
Galium gaudichaudii	-	-	-	-	-	-	-	-	-	-	-	-	-
Geranium solanderi	-	0.07	-	-	-	-	-	1.63	-	-	-	-	-
Glycine spp.	-	0.66	-	-	-	0.06	-	-	-	0.57	-	-	-
Gonocarpus tetragynus	-	-	4.23	3.76	15.13	2.12	3.48	1.32	0.24	0.80	0.44	2.83	10.58
Goodenia hederacea	-	-	0.28	-	8.78	4.28	-	-	0.14	4.94	1.56	0.07	0.34
Goodenia pinnatifida	0.09	-	-	-	-	-	-	-	-	-	-	-	-
Haloragis heterophylla	-	-	1.56	-	0.14	0.38	-	-	0.25	3.04	-	0.09	-
Hibbertia obtusifolia	-	-	-	-	0.53	-	-	-	-	-	-	-	-
Hovea heterophylla	-	-	0.71	-	-	-	-	-	-	3.00	-	-	-
Hydrocotyle laxiflora	-	-	-	5.35	-	0.96	1.60	8.41	0.63	4.84	0.27	0.10	0.77
Hypericum gramineum	-	-	2.23	-	-	0.11	-	0.06	0.01	2.90	-	-	0.02
Isoetopsis graminifolia	-	-	-	-	0.03	-	-	-	-	-	-	-	-
Joycea pallida	-	-	1870	1028	1231	627	26.56	-	41.39	40.74	3.70	-	40.20
Juncus subgen. *Genuini*	0.15	-	7.63	3.96	0.78	-	5.06	5.02	24.50	11.31	6.90	13.06	-
Leptorhynchos squamatus	-	-	-	-	-	-	5.18	-	-	1.65	6.98	12.24	-
Lissanthe strigosa	-	-	-	-	-	-	-	-	-	0.90	-	-	0.20
Lomandra filiformis	18.55	12.15	4.61	7.29	43.03	34.38	18.48	42.48	38.79	24.46	30.77	37.03	11.90
Lomandra multiflora	-	-	-	-	-	5.75	-	-	-	4.08	-	-	-
Luzula spp.	-	-	-	-	-	-	-	-	-	0.02	0.04	1.43	0.93
Lythrum hyssopifolia	-	-	-	-	-	-	-	-	-	-	-	-	-
Melichrus urceolatus	-	-	193.63	13.14	181.15	0.06	-	-	-	26.31	-	-	-
Mentha diemenica	-	-	-	-	-	-	-	-	1.48	-	-	-	-
Microlaena stipoides	0.07	11.75	0.98	5.40	7.15	4.13	0.06	2.19	2.04	2.42	27.08	5.64	0.20
Microseris lanceolata	-	-	-	-	-	-	-	-	-	-	-	-	-
Opercularia hispida	-	-	-	-	-	-	-	-	-	-	-	-	-
Oxalis perennans	0.35	0.02	-	0.11	0.71	0.27	-	-	-	0.04	0.05	0.13	-
Panicum effusum	-	-	1.04	0.36	-	-	-	-	-	-	-	1.82	-
Pimelea curviflora	-	-	-	-	-	0.26	-	-	-	4.45	-	-	-
Pimelea linifolia	-	-	-	-	-	-	-	-	-	-	-	-	-
Plantago gaudichaudii	-	-	-	-	-	-	-	-	-	-	-	-	-
Plantago varia	-	-	-	-	-	-	-	-	-	-	-	-	-

Site code	WG92-3	WG92-4	MF22A-1	MF22A-2	MF22A-3	MF22A-4	MF19A-1	MF19A-2	MF19A-3	MF19A-4	WG81-1	WG81-2	WG81-3
Poa sieberiana	-	-	-	-	-	-	5.25	2.30	7.37	3.70	25.43	3.50	9.67
Pultenaea procumbens	-	-	6.78	-	-	-	-	-	-	-	-	-	-
Ranunculus sessiliflorus	-	-	-	-	-	-	-	-	-	-	-	-	-
Rumex brownii	12.86	0.05	-	-	-	-	-	-	-	-	0.02	0.13	-
Schoenus apogon	-	-	-	-	-	-	-	-	-	-	-	-	1.71
Scleranthus biflorus	-	-	-	-	-	-	-	-	-	-	-	-	-
Senecio hispidulus	-	-	-	-	-	2.37	-	5.42	-	-	-	-	-
Senecio quadridentatus	-	-	-	-	-	-	-	-	-	-	-	-	-
Solenogyne dominii	-	-	0.66	4.16	3.60	1.61	0.80	0.70	1.65	0.10	10.39	10.24	0.29
Stackhousia monogyna	-	-	8.70	-	-	-	-	-	-	-	-	-	-
Stuartina muelleri	-	-	-	0.04	-	-	-	-	-	-	-	-	-
Stylidium graminifolium	-	-	-	-	-	-	-	-	-	-	-	-	-
Thelymitra sp.	-	-	-	-	0.04	-	-	-	-	-	-	-	-
Themeda australis	15.96	1.93	28.24	69.56	26.95	13.40	119	110	90.41	57.48	10.06	69.41	8.11
Thysanotus patersonii	-	-	-	-	-	-	-	-	-	-	-	-	-
Tricoryne elatior	25.12	-	-	0.15	0.28	2.65	0.24	5.15	0.20	5.54	2.00	8.58	-
Triptilodiscus pygmaeus	-	-	9.10	4.10	7.45	0.63	0.02	-	-	0.05	0.02	0.75	0.02
Viola betonicifolia	-	-	-	-	-	-	-	0.02	-	-	-	-	-
Vittadinia cuneata	-	-	-	-	-	-	-	-	-	-	-	-	-
Vittadinia muelleri	-	-	-	-	-	-	-	-	-	-	-	-	0.06
Wahlenbergia spp.	0.06	-	-	-	-	-	-	0.06	-	-	0.19	0.02	4.13
Wurmbea dioica	-	-	-	0.21	-	-	0.06	-	-	0.01	-	-	0.27
d) Exotic plant species (kg ha^{-1})													
Acetosella vulgaris	-	-	-	-	-	-	-	-	-	-	0.06	-	-
Aira spp.	1.28	0.08	5.51	1.08	4.39	1.05	0.07	-	0.42	0.15	0.20	4.33	0.13
Anagallis arvensis	-	-	-	-	-	0.06	-	-	-	-	-	-	-
Aphanes arvensis	0.02	-	-	-	-	-	-	-	-	-	-	-	-
Arctotheca calendula	0.97	21.60	-	-	-	-	-	-	-	-	1.15	0.09	0.34
Briza maxima	-	-	-	-	0.02	-	-	-	-	-	-	-	-
Briza minor	0.02	-	0.67	2.78	3.13	1.88	-	-	-	-	0.02	-	0.06
Bromus diandrus	-	0.90	-	-	-	-	-	-	2.71	-	3.27	-	-
Bromus hordeaceus	24.90	1.69	-	-	-	-	-	-	1.35	0.02	0.59	1.12	-
Bromus rubens	-	1.23	-	-	-	-	-	-	-	-	-	-	-
Carduus pycnocephalus	-	-	-	-	-	-	-	-	39.13	-	-	-	-
Carthamus lanatus	-	-	-	-	-	-	-	-	-	-	-	-	-
Centaurium erythraea	-	-	-	-	-	-	-	-	-	-	-	-	-
Chondrilla juncea	-	6.22	-	-	-	-	-	-	-	-	-	-	-
Cicendia quadrangularis	-	-	-	-	-	-	-	-	-	-	-	-	-
Echium plantagineum	-	0.71	-	-	-	-	-	-	-	-	-	-	-
Erodium botrys	-	-	-	-	-	-	-	-	-	-	-	-	-
Erodium cicutarium	0.60	0.07	-	-	-	-	-	-	-	-	-	-	-
Galium divaricatum	-	-	0.04	0.11	0.19	-	-	-	-	-	0.02	-	0.07
Galium murale	-	-	-	-	-	-	-	-	-	-	-	-	-
Gamochaeta americana	-	-	-	-	-	-	-	-	-	-	-	-	-
Gypsophila tubulosa	-	-	-	-	-	-	-	-	-	-	-	-	-
Hordeum sp.	-	1.48	-	-	-	-	-	-	-	-	-	-	-
Hypericum perforatum	-	4.30	-	-	-	-	-	-	-	-	-	-	-
Hypochaeris glabra	-	-	-	-	0.97	-	7.42	0.19	0.06	0.55	-	0.93	-
Hypochaeris radicata	10.91	10.36	0.69	8.24	11.65	17.85	-	-	5.69	0.15	0.05	-	-
Lactuca serriola	-	-	-	-	-	-	-	-	-	-	-	-	-
Linaria arvensis	-	-	-	-	-	-	-	-	-	-	-	-	-
Linaria pelisseriana	-	-	-	0.05	-	-	-	-	-	-	-	-	-
Linum trigynum	-	-	-	-	-	-	-	-	-	-	-	-	-
Logfia gallica	-	-	0.01	-	0.25	0.04	-	-	-	-	-	-	-
Lolium spp.	0.11	31.03	-	-	-	-	0.26	-	-	-	3.28	1.76	-
Modiola caroliniana	-	-	-	-	-	-	-	-	-	-	-	-	-
Moenchia erecta	0.02	-	-	-	0.10	-	-	-	0.09	-	-	-	-
Myosotis discolor	-	-	-	-	-	-	-	-	0.26	-	-	-	-
Nassella trichotoma	-	-	-	-	-	-	-	-	-	-	-	-	-
Paronychia brasiliana	0.15	-	-	-	-	-	-	-	-	0.45	-	-	-
Paspalum dilatatum	-	-	-	-	-	-	-	-	-	-	-	-	-
Petrorhagia nanteuilii	-	-	-	-	-	-	0.08	0.17	-	0.08	-	0.11	-
Phalaris aquatica	-	-	-	-	-	-	-	-	-	-	-	-	-
Plantago coronopus	-	-	-	-	0.47	-	-	-	-	-	-	-	-
Plantago lanceolata	-	-	-	-	-	-	-	-	-	-	-	-	-
Poa bulbosa	5.82	1.25	-	-	-	-	-	-	0.05	-	-	-	4.22
Romulea rosea	-	-	-	-	-	0.47	-	-	-	-	-	-	-

Site code	WG92-3	WG92-4	MF22A-1	MF22A-2	MF22A-3	MF22A-4	MF19A-1	MF19A-2	MF19A-3	MF19A-4	WG81-1	WG81-2	WG81-3
Rosa rubiginosa	-	-	-	-	-	-	-	-	-	-	-	-	-
Salvia verbenaca	-	3.67	-	-	-	-	-	-	-	-	-	-	-
Sherardia arvensis	-	-	-	-	0.06	-	-	-	-	-	-	-	-
Silene gallica	-	-	-	-	-	-	-	-	-	-	-	-	-
Sisymbrium officinale	-	-	-	-	-	-	-	-	-	-	-	-	-
Soliva sessilis	-	-	-	-	-	-	-	-	-	-	-	-	-
Tolpis barbata	-	-	0.02	-	0.02	0.13	-	-	-	-	-	-	-
Trifolium angustifolium	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifolium arvense	0.03	0.09	-	-	0.18	-	-	-	-	-	0.35	0.75	0.04
Trifolium campestre	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifolium dubium	0.09	-	-	-	-	0.04	-	-	-	0.02	-	-	-
Trifolium glomeratum	35.31	2.61	-	-	0.60	-	-	-	-	-	-	-	-
Trifolium striatum	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifolium subterraneum	46.13	26.90	0.40	0.13	3.07	1.78	0.05	-	-	0.03	0.02	0.20	-
Vulpia spp.	0.02	0.06	0.59	0.47	0.03	-	1.67	3.96	0.15	0.40	0.14	-	0.63

Site code	WG81-4	WG150A-1	WG150A-2	WG150A-3	WG150A-4	MF32-1	MF32-2	MF32-3	MF32-4	WG63-1	WG63-2	WG63-3	WG63-4
Floristic group	2	6	6	6	6	5	2	2	3	2	2	4	2
a) Ground cover attributes													
Total biomass kgha^{-1}	612	320	349	369	329	512	264	267	578	501	462	531	390
Live plant basal area % .	16.7	9.2	14.2	13.3	11.7	16.7	19.2	23.3	15.8	10.8	7.5	10.8	4.2
Litter %	62.5	79.2	72.5	75.0	84.2	69.2	40.8	46.7	32.5	78.3	70.8	73.3	70.8
Litter depth where present (mm)	12.8	8.1	10.2	10.1	13.8	14.3	14.4	16.1	17.4	8.0	12.1	10.0	16.9
Bare ground %	10.8	6.7	3.3	6.7	1.7	9.2	28.3	30.0	39.2	5.8	19.2	8.3	18.3
Fallen log %	2.5	2.5	1.7	0.8	-	1.7	4.2	-	-	0.8	1.7	4.2	-
Cryptogam %	7.5	1.7	8.3	4.2	1.7	3.3	7.5	-	12.5	4.2	0.8	3.3	4.2
Rock %	-	0.8	-	-	0.8	-	-	-	-	-	-	-	2.5
b) Soil attributes (0 - 10 cm)													
Nitrate-N (mgkg^{-1})	<0.25	1.6	11.0	4.1	3.9	8.9	1.4	1.3	1.9	0.4	1.0	1.0	<0.25
Carbon (%)	2.0	2.3	2.6	2.5	2.6	3.8	2.8	2.7	2.4	1.6	2.2	2.1	2.6
Nitrogen (%)	0.1	0.1	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Electrical conductivity (dSm^{-1})	<0.05	<0.05	0.1	<0.05	0.1	0.1	<0.05	<0.05	<0.05	<0.05	0.1	0.1	0.1
pH(CaCl2)	4.2	4.4	4.8	4.5	4.5	4.5	4.4	4.4	4.2	4.5	4.8	4.9	4.9
pH(water)	5.1	5.2	5.6	5.3	5.4	5.2	5.1	5.3	5.1	5.4	5.5	5.6	5.6
Available phosphorous (mgkg^{-1})	<4	5.0	7.0	6.0	12.0	10.0	8.0	6.0	7.0	<4	6.0	6.0	7.0
c) Native plant species (kg ha^{-1})													
Acacia dealbata	-	-	-	-	-	-	-	-	-	-	-	-	-
Acacia gunnii	-	-	-	-	-	-	-	-	-	-	-	-	-
Acacia parramattensis	-	-	-	-	-	-	-	-	-	-	-	-	-
Acaena ovina	-	0.08	-	0.06	0.62	-	2.68	3.22	-	15.12	-	1.20	2.38
Alternanthera sp. A	-	0.01	-	-	0.05	-	0.20	-	-	-	-	-	-
Aristida ramasa	288	-	14.93	18.05	-	222	6.09	1.19	45.60	103	36.22	32.64	45.05
Arthropodium minus	0.01	-	-	-	-	-	-	-	-	-	-	-	0.07
Asperula conferta	-	-	-	-	-	-	-	9.39	-	-	0.83	-	0.08
Astroloma humifusum	-	-	-	-	-	-	-	-	-	-	-	-	-
Austrodanthonia spp.	52.66	10.06	73.87	73.27	86.24	100	108	102	43.64	178	108	92.08	124
Austrostipa bigeniculata	-	-	-	-	-	-	-	-	-	-	-	-	-
Austrostipa densiflora	5.88	-	109	18.13	-	-		-	-	88.15	-	22.24	42.25
Austrostipa scabra	-	0.03	-	10.41	1.56	0.33	051	-	-	0.87	18.09	2.96	-
Bossiaea buxifalia	-	-	-	-	-	-	-	-	-	-	8.20	-	-
Bossiaea prostrata	-	-	-	-	-	-	-	-	-	-	-	-	-
Bothriochloa macra	-	64.95	0.22	45.69	27.48	17.58	12.02	1.91	-	5.79	21.87	0.16	4.74
Brachyloma daphnoides	-	-	-	-	-	-	-	-	-	-	-	-	-
Bulbine bulbosa	-	-	-	-	-	-	-	0.25	-	-	0.87	0.20	-
Carex inversa	-	0.20	-	0.27	6.29	-	-	-	-	1.10	6.69	0.04	-
Chamaesyce drummondii	-	-	-	-	-	-	-	-	-	0.36	-	-	-
Cheilanthes spp.	-	-	0.20	1.66	-	-	3.58	-	0.10	2.42	-	-	-
Chloris truncata	-	-	-	-	-	0.86	0.56	-	-	2.79	-	-	0.07
Chrysocephalum apiculatum	-	-	-	-	-	-	-	-	-	-	-	3.06	15.49
Chrysocephalum semipapposum	-	-	-	-	-	-	-	-	-	-	-	-	-
Convolvulus angustissimus	-	-	-	-	-	-	-	-	-	-	14.48	0.25	0.90
Cotula australis	-	-	-	-	-	0.07	-	-	-	-	0.65	-	-

Site code	WG81-4	WG150A-1	WG150A-2	WG150A-3	WG150A-4	MF32-1	MF32-2	MF32-3	MF32-4	WG63-1	WG63-2	WG63-3	WG63-4
Craspedia variabilis	-	-	-	-	-	-	-	-	-	-	-	-	-
Crassula sieberiana	0.02	0.15	-	0.05	0.16	-	-	-	-	-	-	-	-
Cymbonotus spp.	-	-	-	-	-	0.02	-	-	-	-	-	-	7.19
Cynodon dactylon	-	-	-	-	-	0.13	-	-	-	-	-	-	-
Cynoglossum suaveolens	-	-	-	-	-	-	-	-	-	-	-	-	-
Daucus glochidiatus	-	-	-	-	-	0.14	0.02	0.26	-	-	-	-	0.03
Daviesia genistifolia	-	-	-	-	-	9.15	-	-	-	-	-	-	-
Desmodium varians	3.15	-	-	-	-	-	-	-	-	-	0.24	1.21	5.45
Dianella revoluta	-	-	-	-	-	-	-	-	-	-	-	-	-
Dichelachne spp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Dichopogon fimbriatus	-	-	-	-	-	-	-	-	-	7.31	0.08	1.24	0.10
Dillwynia sericea	39.49	-	-	-	-	-	-	-	3.71	-	-	-	-
Diuris sulphurea	-	-	-	-	-	-	-	-	-	-	-	-	-
Drosera peltata	-	-	-	-	-	-	-	-	-	-	-	-	-
Einadia nutans	-	-	-	-	-	0.06	-	-	-	4.49	-	7.27	-
Eleocharis acuta	-	-	-	-	-	-	-	-	-	-	-	-	-
Elymus scaber	1.19	4.26	8.53	21.80	18.01	3.65	0.23	0.62	0.03	4.30	2.25	14.36	6.24
Enneapogon nigricans	-	-	-	-	-	-	-	-	-	-	-	-	-
Eragrostis brownii	-	-	-	-	-	-	-	0.18	-	-	-	-	-
Erodium crinitum	-	-	-	-	-	-	-	-	-	-	-	-	-
Eryngium rostratum	-	-	-	-	-	-	-	-	-	-	-	-	-
Euchiton gymnocephalus	-	-	-	-	-	-	-	-	-	-	-	-	-
Euchiton sphaericus	-	-	-	0.02	-	-	-	-	-	-	-	-	-
Galium gaudichaudii	-	-	-	-	-	-	-	-	-	-	-	-	-
Geranium solanderi	0.04	0.80	-	-	0.43	0.20	0.04	0.04	-	1.59	0.53	-	-
Glycine spp.	-	-	-	-	-	-	-	-	-	-	1.12	-	2.84
Gonocarpus tetragynus	14.94	-	-	0.02	-	-	6.69	6.39	1.68	0.91	0.80	0.81	2.02
Goodenia hederacea	4.01	-	-	-	-	-	0.01	0.01	0.14	0.38	0.02	0.62	-
Goodenia pinnatifida	-	-	-	-	-	-	-	-	-	-	-	-	-
Haloragis heterophylla	-	-	-	-	-	0.06	0.23	0.22	0.76	-	-	-	-
Hibbertia obtusifolia	34.32	-	-	-	-	-	-	-	-	-	-	-	2.23
Hovea heterophylla	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydrocotyle laxiflora	1.01	0.08	-	-	-	1.68	0.95	1.24	0.06	2.56	2.56	0.99	6.46
Hypericum gramineum	-	-	0.06	-	-	-	0.04	1.79	0.43	0.44	0.20	-	0.24
Isoetopsis graminifolia	-	-	-	-	-	-	-	-	-	-	-	-	-
Joycea pallida	-	-	0.15	-	-	133	2.03	6.92	357	-	-	-	-
Juncus subgen. *Genuini*	0.78	0.98	4.52	7.49	2.38	0.12	-	1.47	-	0.12	1.65	-	10.03
Leptorhynchos squamatus	3.93	-	-	-	-	0.45	-	-	2.22	0.05	0.19	2.76	14.93
Lissanthe strigosa	53.81	-	-	-	-	-	-	-	-	-	-	92.66	-
Lomandra filiformis	20.11	20.27	9.65	-	-	13.48	11.59	10.55	11.60	7.45	10.49	21.29	3.00
Lomandra multiflora	-	-	-	-	-	6.18	0.53	-	5.93	-	-	-	-
Luzula spp.	0.24	-	-	-	-	0.29	-	-	-	-	-	-	0.58
Lythrum hyssopifolia	-	-	0.17	-	-	-	-	-	-	-	-	-	-
Melichrus urceolatus	-	-	-	-	-	141.26	-	-	4.02	-	-	-	-
Mentha diemenica	-	-	-	-	-	-	-	-	-	-	0.92	-	-
Microlaena stipoides	1.04	38.52	18.75	17.53	2.37	-	-	4.25	-	-	2.66	-	-
Microseris lanceolata	-	-	-	-	-	-	-	-	-	-	-	-	-
Opercularia hispida	-	-	-	-	-	-	-	-	-	-	-	-	-
Oxalis perennans	0.42	-	0.06	1.13	0.29	1.75	1.54	-	-	0.36	0.85	0.06	0.38
Panicum effusum	-	-	13.82	11.25	-	5.01	6.68	1.77	-	3.06	-	-	1.48
Pimelea curviflora	-	-	-	-	-	-	-	-	-	-	-	-	-
Pimelea linifolia	-	-	-	-	-	-	-	-	-	-	-	-	-
Plantago gaudichaudii	-	-	-	-	-	-	-	-	-	-	-	-	0.03
Plantago varia	-	-	-	-	-	-	-	-	-	-	1.27	26.26	20.78
Poa sieberiana	6.30	-	-	-	-	7.07	-	-	2.14	-	-	-	0.03
Pultenaea procumbens	-	-	-	-	-	-	-	-	-	-	-	-	-
Ranunculus sessiliflorus	-	-	-	-	-	-	-	-	-	-	-	-	-
Rumex brownii	-	2.82	-	-	0.42	-	-	-	-	-	-	-	-
Schoenus apogon	-	-	-	-	-	-	-	-	-	-	-	-	-
Scleranthus biflorus	-	-	0.10	-	-	-	-	-	-	-	-	-	-
Senecio hispidulus	-	-	-	-	-	-	-	-	-	-	-	-	-
Senecio quadridentatus	-	-	-	-	-	-	-	-	-	-	-	-	-
Solenogyne dominii	0.92	1.04	-	1.13	0.13	3.25	1.18	1.30	1.17	-	0.24	0.26	0.09
Stackhousia monogyna	-	-	-	-	-	-	-	-	-	-	-	0.92	-
Stuartina muelleri	-	-	-	-	-	-	-	-	-	-	-	-	-
Stylidium graminifolium	-	-	-	-	-	-	-	-	-	-	-	-	-
Thelymitra sp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Themeda australis	58.65	-	-	-	-	10.63	60.26	91.72	65.81	37.89	84.48	166	22.75
Thysanotus patersonii	0.07	-	-	-	-	-	-	-	-	-	-	-	-
Tricoryne elatior	-	-	-	-	0.10	0.01	0.23	4.75	8.59	18.55	10.52	3.20	2.01

Site code	WG81-4	WG150A-1	WG150A-2	WG150A-3	WG150A-4	MF32-1	MF32-2	MF32-3	MF32-4	WG63-1	WG63-2	WG63-3	WG63-4
Triptilodiscus pygmaeus	-	-	-	-	-	2.62	5.52	4.73	4.84	1.42	-	0.05	-
Viola betonicifolia	-	-	-	-	-	-	-	-	-	-	-	3.21	-
Vittadinia cuneata	-	-	-	-	-	-	-	-	-	-	-	-	-
Vittadinia muelleri	-	-	-	-	-	-	6.18	-	-	-	-	-	-
Wahlenbergia spp.	2.14	-	-	-	0.01	0.14	0.41	0.96	-	1.07	1.41	0.85	1.53
Wurmbea dioica	-	-	-	-	-	-	-	0.36	0.71	0.24	-	0.11	-
d) Exotic plant species (kg ha^{-1})													
Acetosella vulgaris	-	-	1.03	1.94	12.62	-	-	0.06	-	-	3.47	6.31	-
Aira spp.	1.89	0.04	3.05	0.21	0.12	0.55	0.15	0.34	1.22	2.40	0.19	1.09	0.04
Anagallis arvensis	-	0.07	-	-	-	-	-	-	-	-	-	-	-
Aphanes arvensis	-	-	-	-	-	-	-	-	-	-	-	-	-
Arctotheca calendula	-	35.61	4.45	5.59	4.48	9.93	0.02	-	0.12	-	0.11	-	0.81
Briza maxima	-	-	-	-	-	-	-	-	1.26	-	-	-	-
Briza minor	-	0.28	0.31	0.02	0.90	-	0.04	0.02	0.29	0.30	0.54	0.16	-
Bromus diandrus	-	-	0.06	0.05	0.91	0.05	4.82	-	-	-	0.18	6.99	0.85
Bromus hordeaceus	0.27	1.38	8.59	2.73	8.99	0.18	0.23	0.73	-	-	0.11	0.84	0.27
Bromus rubens	-	-	-	-	-	-	-	-	-	-	-	-	0.26
Carduus pycnocephalus	-	-	-	-	-	-	-	-	-	-	-	-	-
Carthamus lanatus	-	-	-	-	-	-	-	-	-	-	-	-	-
Centaurium erythraea	-	-	-	-	-	-	-	-	-	-	-	-	-
Chondrilla juncea	-	-	-	-	-	-	-	-	-	0.92	15.18	0.27	10.00
Cicendia quadrangularis	-	-	-	-	-	-	0.07	-	3.22	-	-	-	-
Echium plantagineum	-	-	-	-	-	-	-	-	-	-	-	-	-
Erodium botrys	-	-	0.06	-	-	-	-	-	-	-	-	-	-
Erodium cicutarium	-	0.06	-	-	-	2.18	-	-	-	-	-	-	-
Galium divaricatum	2.60	0.01	-	-	-	0.15	8.01	0.57	0.20	-	-	-	-
Galium murale	-	-	-	-	-	-	-	-	-	-	-	-	-
Gamochaeta americana	-	-	-	-	-	-	-	-	-	-	-	-	-
Gypsophila tubulosa	-	-	-	-	-	-	-	-	-	-	-	-	-
Hordeum sp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hypericum perforatum	-	-	-	-	-	-	-	-	-	-	-	-	-
Hypochaeris glabra	0.06	0.88	0.36	0.67	-	0.56	4.03	1.74	4.05	0.91	0.32	0.22	0.22
Hypochaeris radicata	0.40	12.76	0.62	0.23	0.06	-	1.45	-	0.04	2.84	0.08	0.25	-
Lactuca serriola	-	-	-	-	-	-	-	-	-	-	-	-	-
Linaria arvensis	-	-	-	-	-	-	-	-	-	-	-	-	-
Linaria pelisseriana	-	-	-	-	-	-	-	-	-	-	-	-	-
Linum trigynum	-	-	-	-	-	-	-	-	-	-	-	-	-
Logfia gallica	-	-	-	0.07	-	-	0.01	-	1.71	-	-	0.81	0.22
Lolium spp.	11.33	4.36	29.05	17.38	38.22	-	-	-	-	0.02	36.59	3.98	18.58
Modiola caroliniana	-	-	-	-	-	-	-	-	-	-	-	-	-
Moenchia erecta	-	0.06	0.04	0.02	0.27	-	-	-	-	-	-	-	-
Myosotis discolor	-	0.03	-	-	-	-	-	-	-	-	-	-	-
Nassella trichotoma	-	-	-	-	-	-	-	-	-	-	-	1.93	-
Paronychia brasiliana	-	-	-	-	-	-	-	-	-	-	-	-	-
Paspalum dilatatum	-	-	-	-	-	-	-	-	-	-	-	-	-
Petrorhagia nanteuilii	0.78	0.03	-	-	-	0.03	-	-	-	-	0.17	0.03	1.85
Phalaris aquatica	-	47.43	25.80	59.16	55.58	-	-	-	-	-	33.58	-	-
Plantago coronopus	-	-	-	-	-	-	-	-	-	-	-	-	-
Plantago lanceolata	-	-	-	-	-	-	-	-	-	-	-	-	-
Poa bulbosa	-	-	-	-	1.45	-	-	-	-	-	2.80	-	1.04
Romulea rosea	-	-	-	-	-	-	-	-	-	-	-	-	-
Rosa rubiginosa	-	-	-	-	-	-	-	-	-	-	-	-	-
Salvia verbenaca	-	-	-	-	-	-	-	-	-	-	-	-	-
Sherardia arvensis	-	0.02	-	-	-	-	-	-	-	-	-	-	-
Silene gallica	-	-	-	-	-	-	-	-	-	-	-	-	-
Sisymbrium officinale	-	-	-	-	-	-	-	-	-	-	-	-	-
Soliva sessilis	-	-	-	-	-	-	-	-	-	-	-	-	-
Tolpis barbata	-	-	-	-	-	-	1.87	0.22	-	0.06	-	-	-
Trifolium angustifolium	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifolium arvense	0.92	-	-	-	-	0.13	0.20	0.05	-	1.91	12.14	1.80	0.11
Trifolium campestre	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifolium dubium	-	0.66	0.06	0.84	-	19.29	-	0.25	2.38	-	-	-	0.21
Trifolium glomeratum	-	1.11	-	0.67	-	2.37	0.11	0.89	-	-	0.03	-	0.21
Trifolium striatum	-	-	-	-	-	0.56	-	-	-	-	-	-	-
Trifolium subterraneum	0.31	68.97	19.13	50.61	45.83	7.89	3.02	3.16	0.08	0.21	0.21	0.26	0.34
Vulpia spp.	0.08	1.60	0.55	0.47	7.83	1.19	0.04	-	0.15	0.61	6.54	0.11	0.34

Site code	WG76-1	WG76-2	WG76-3	WG76-4	WG109-1	WG109-2	WG109-3	WG109-4	MF37-1	MF37-2	MF37-3	MF37-4	MF25A-1
Floristic group	3	4	2	2	1	1	1	1	2	3	2	5	2
a) Ground cover attributes													
Total biomass kgha^{-1}	602	359	415	308	457	458	947	834	834	849	495	599	436
Live plant basal area %	7.5	7.5	5.8	5.0	10.0	8.3	14.2	8.3	15.8	15.0	8.3	10.0	10.8
Litter %	75.0	67.5	77.5	75.8	78.3	77.5	77.5	60.8	62.5	65.0	62.5	73.3	75.0
Litter depth where present (mm)	11.4	10.3	13.5	14.3	17.3	14.5	12.8	13.4	6.6	16.1	13.6	13.8	10.5
Bare ground %	10.8	19.2	10.8	12.5	3.3	6.7	8.3	19.2	20.0	15.0	19.2	8.3	4.2
Fallen log %	-	5.0	1.7	1.7	3.3	5.0	-	8.3	-	-	3.3	-	0.8
Cryptogam %	0.8	0.8	3.3	1.7	5.0	2.5	-	0.8	1.7	5.0	6.7	8.3	9.2
Rock %	5.8	-	0.8	3.3	-	-	-	2.5	-	-	-	-	-
b) Soil attributes (0 - 10 cm)													
Nitrate-N (mgkg^{-1})	0.4	0.5	0.6	2.4	9.9	9.0	2.9	11.0	1.3	0.7	1.5	0.4	<0.25
Carbon (%)	2.8	2.3	2.6	2.8	4.2	3.6	3.0	4.7	3.0	2.6	2.9	2.7	2.5
Nitrogen (%)	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.2	0.1	0.2	0.1	0.1
Electrical conductivity (dSm^{-1})	0.1	<0.05	0.1	0.1	0.1	0.1	<0.05	0.1	<0.05	<0.05	0.1	<0.05	0.1
pH(CaCl2)	4.6	4.8	4.9	4.9	4.3	4.4	4.3	4.3	4.6	4.5	4.7	4.5	4.2
pH(water)	5.3	5.6	5.7	5.7	5.0	5.0	5.1	5.0	5.4	5.3	5.4	5.3	5.0
Available phosphorous (mgkg^{-1})	6.0	5.0	5.0	6.0	18.0	13.0	10.0	23.0	9.0	6.0	10.0	8.0	<4
c) Native plant species (kg ha^{-1})													
Acacia dealbata	-	-	-	-	-	-	-	-	-	0.03	-	-	-
Acacia gunnii	-	-	-	-	-	-	-	-	-	-	-	-	-
Acacia parramattensis	-	-	-	-	-	-	-	-	-	-	-	-	-
Acaena ovina	5.93	1.19	0.21	0.02	-	-	-	-	5.48	3.26	-	2.84	-
Alternanthera sp. *A*	-	0.62	-	0.15	-	-	0.31	-	-	-	-	-	-
Aristida ramosa	27.29	27.39	141.42	108.29	-	0.80	-	-	8.20	2.68	-	19.47	12.65
Arthropodium minus	-	-	0.04	-	-	-	-	-	-	-	-	-	-
Asperula conferta	-	-	-	1.28	-	-	-	-	-	-	-	-	11.97
Astroloma humifusum	13.48	-	-	-	-	-	-	-	-	-	-	-	-
Austrodanthonia spp.	14.51	42.30	62.85	67.05	193	168	215	74.68	179	80.40	168	167	192
Austrostipa bigeniculata	-	1.25	-	-	-	-	127	4.94	-	-	-	-	-
Austrostipa densiflora	2.07	-	10.19	4.95	55.45	16.55	32.29	11.67	-	-	-	-	-
Austrostipa scabra	0.89	2.08	2.59	10.31	37.45	89.10	97.89	87.72	9.71	2.80	18.93	-	-
Bossiaea buxifolia	0.38	-	-	-	-	-	-	-	-	1.51	-	-	-
Bossiaea prostrata	0.32	-	0.25	-	-	-	-	-	-	6.44	-	-	-
Bothriochloa macra	0.22	4.74	36.50	20.51	0.27	-	0.99	6.30	48.47	19.10	59.11	30.60	9.20
Brachyloma daphnoides	-	-	-	-	-	-	-	-	-	-	-	-	-
Bulbine bulbosa	-	-	-	-	-	-	-	-	-	-	-	-	-
Carex inversa	0.72	0.59	-	5.82	-	7.47	0.75	0.14	0.24	-	-	0.23	2.76
Chamaesyce drummondii	-	-	-	-	-	-	-	-	-	0.10	-	-	0.93
Cheilanthes spp.	0.08	-	0.73	1.63	-	-	-	-	0.25	-	-	-	-
Chloris truncata	-	-	-	-	-	-	0.11	-	-	0.26	0.26	3.91	3.57
Chrysocephalum apiculatum	-	-	-	-	-	-	-	-	-	-	-	-	-
Chrysocephalum semipapposum	-	-	-	-	-	-	-	-	-	-	-	-	-
Convolvulus angustissimus	0.05	-	-	-	-	-	-	-	-	-	-	-	-
Cotula australis	-	-	-	-	-	-	-	0.33	-	-	-	-	-
Craspedia variabilis	-	4.42	-	-	-	-	-	-	-	-	7.19	0.04	-
Crassula sieberiana	-	-	-	-	1.50	1.45	1.04	0.78	-	-	-	-	-
Cymbonatus spp.	-	0.88	-	-	-	0.82	-	-	-	-	-	-	-
Cynodon dactylon	-	-	-	-	-	-	-	-	-	-	-	-	-
Cynoglossum suavealens	-	-	-	-	-	-	-	-	-	-	-	-	-
Daucus glochidiatus	0.16	0.52	0.18	0.04	-	-	-	-	3.29	0.30	0.03	0.38	0.09
Daviesia genistifalia	0.82	-	-	-	-	-	-	-	-	-	-	-	-
Desmodium varians	1.32	0.59	0.89	0.71	1.04	0.14	0.65	-	-	-	-	-	-
Dianella revaluta	-	-	-	-	-	-	-	-	-	-	-	-	-
Dichelachne spp.	-	-	-	-	0.36	-	-	-	-	-	-	-	-
Dichopogon fimbriatus	-	-	-	-	-	-	-	-	-	-	0.43	-	0.99
Dillwynia sericea	9.39	-	-	-	-	-	-	-	-	3.37	-	-	-
Diuris sulphurea	-	-	-	-	-	-	-	-	-	-	-	-	-
Drosera peltata	-	-	-	-	-	-	-	-	-	-	-	-	-
Einadia nutans	-	-	-	-	4.23	2.74	-	20.12	-	-	38.47	-	-
Eleocharis acuta	-	-	-	-	-	-	-	-	-	-	-	-	-
Elymus scaber	0.19	4.97	1.13	0.86	49.98	26.60	3.99	9.20	0.85	1.84	8.70	1.75	35.73
Enneapogon nigricans	0.02	-	-	5.19	-	-	-	-	-	0.29	-	-	-
Eragrostis brownii	-	-	-	-	-	-	-	-	-	-	-	-	0.28
Erodium crinitum	-	-	-	-	-	0.52	-	0.89	-	-	-	-	-
Eryngium rostratum	-	-	-	-	-	-	-	-	-	-	-	-	-
Euchiton gymnocephalus	-	-	-	-	-	-	-	-	-	-	-	-	-

Site code	WG76-1	WG76-2	WG76-3	WG76-4	WG109-1	WG109-2	WG109-3	WG109-4	MF37-1	MF37-2	MF37-3	MF37-4	MF25A-1
Euchiton sphaericus	-	-	-	-	-	0.41	-	-	0.03	-	-	0.04	0.28
Galium gaudichaudii	1.26	-	-	-	-	-	-	-	-	-	-	-	-
Geranium salanderi	-	-	-	-	-	-	-	-	1.85	0.03	-	-	-
Glycine spp.	0.12	0.29	1.88	0.98	-	-	-	-	-	-	-	-	-
Gonocarpus tetragynus	7.33	0.16	0.13	-	0.36	-	-	-	1.64	2.00	-	0.94	0.03
Goodenia hederacea	0.98	-	-	-	-	-	-	-	0.08	4.69	-	0.60	-
Goodenia pinnatifida	-	-	-	0.29	-	-	-	-	-	-	-	-	-
Haloragis heterophylla	-	0.16	0.18	5.83	-	-	-	-	-	-	0.13	-	0.93
Hibbertia obtusifolia	-	-	-	-	-	-	-	-	-	-	-	-	-
Hovea heterophylla	-	-	-	-	-	-	-	-	-	2.69	-	-	-
Hydrocotyle laxiflora	3.41	3.02	3.02	0.58	-	-	-	-	1.43	2.16	5.20	5.72	10.67
Hypericum gramineum	0.11	-	-	0.25	-	-	-	-	-	0.62	4.57	4.49	0.62
Isoetopsis graminifolia	-	-	-	-	-	-	-	-	-	-	-	-	-
Joycea pallida	296	-	-	0.80	-	-	-	-	-	483	-	144	-
Juncus subgen. *Genuini*	0.34	6.48	4.27	6.39	-	0.24	-	-	0.92	5.23	0.19	8.71	22.72
Leptorhynchos squamatus	5.12	6.97	0.18	0.02	-	-	-	-	0.03	-	0.22	-	-
Lissanthe strigosa	-	-	-	-	-	-	-	-	375	1.55	86.12	-	-
Lomandra filiformis	75.52	31.65	78.39	10.73	-	20.55	-	-	8.60	19.94	14.65	28.02	28.86
Lomandra multiflora	-	-	-	-	-	-	-	-	-	-	-	-	-
Luzula spp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Lythrum hyssopifolia	-	-	-	0.42	-	-	-	-	-	-	-	-	-
Melichrus urceolatus	36.50	3.85	-	-	-	-	-	-	-	-	-	-	-
Mentha diemenica	-	-	-	0.17	-	-	-	-	-	-	-	-	-
Microlaena stipoides	-	29.15	1.41	23.19	-	9.64	38.08	0.09	-	-	15.23	10.21	12.11
Microseris lanceolata	0.09	-	-	-	-	-	-	-	-	-	-	-	-
Opercularia hispida	-	-	-	-	-	-	-	-	-	-	-	-	-
Oxalis perennans	0.02	0.05	0.02	-	0.27	2.02	-	0.14	1.55	0.11	0.26	1.21	1.28
Panicum effusum	-	0.24	0.16	0.64	-	-	1.23	0.32	3.67	3.21	10.59	4.08	9.95
Pimelea curviflora	-	-	-	-	-	-	-	-	-	1.66	-	2.53	-
Pimelea linifolia	-	-	-	-	-	-	-	-	-	-	-	-	-
Plantago gaudichaudii	-	-	-	-	-	-	-	-	-	-	-	-	0.83
Plantago varia	0.51	-	-	-	-	-	-	-	-	-	-	-	-
Poa sieberiana	14.68	66.37	48.05	10.05	-	-	-	-	3.89	7.63	7.70	-	13.27
Pultenaea procumbens	-	-	-	-	-	-	-	-	-	-	-	-	-
Ranunculus sessiliflorus	-	-	-	-	-	-	-	-	-	-	-	-	-
Rumex brownii	-	-	-	-	1.16	-	0.28	0.58	-	-	-	-	-
Schoenus apogon	-	-	-	-	-	-	-	-	-	-	-	-	-
Scleranthus biflorus	-	-	-	-	-	-	-	-	-	-	-	1.03	-
Senecio hispidulus	-	-	-	-	-	-	-	-	-	-	-	-	-
Senecio quadridentatus	-	-	-	-	-	-	-	-	-	-	-	-	-
Solenogyne dominii	-	7.64	0.81	1.55	-	-	-	-	2.99	1.29	1.54	2.71	7.56
Stackhousia monogyna	1.04	-	-	-	-	-	-	-	-	-	-	-	-
Stuartina muelleri	-	-	-	-	-	-	-	-	-	-	-	-	-
Stylidium graminifolium	-	-	-	-	-	-	-	-	-	-	-	-	-
Thelymitra sp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Themeda australis	76.69	106	9.33	16.89	-	-	12.70	-	67.76	113	11.40	106	27.27
Thysanotus patersonii	-	-	-	-	-	-	-	-	-	-	-	-	-
Tricoryne elatior	-	-	-	0.69	-	-	-	-	0.11	0.32	0.11	1.42	1.78
Triptilodiscus pygmaeus	0.21	0.10	0.05	-	-	-	-	-	0.72	0.03	0.03	1.51	0.13
Viola betonicifolia	-	0.98	-	-	-	-	-	-	-	-	-	-	-
Vittadinia cuneata	-	-	-	-	-	-	-	-	-	-	1.05	-	-
Vittadinia muelleri	-	-	-	0.05	-	-	-	-	0.94	10.71	14.07	20.45	-
Wahlenbergia spp.	0.69	0.45	0.22	0.20	-	-	-	-	0.04	0.03	0.99	0.56	0.30
Wurmbea dioica	0.07	-	0.39	-	-	-	-	-	-	-	-	-	-
d) Exotic plant species (kg ha $^{-1}$)													
Acetosella vulgaris	-	-	-	-	0.48	0.03	-	2.41	12.22	4.34	-	-	-
Aira spp.	-	0.18	-	-	-	0.08	0.78	-	0.14	0.12	0.10	0.43	0.48
Anagallis arvensis	-	-	-	0.05	-	-	-	-	2.06	-	-	0.13	1.15
Aphanes arvensis	-	-	-	-	-	-	-	-	-	-	-	-	-
Arctotheca calendula	-	-	0.07	0.04	28.15	20.59	10.93	32.82	3.31	-	0.33	-	-
Briza maxima	-	-	-	-	-	-	-	-	0.09	-	-	0.28	-
Briza minor	-	0.20	0.06	0.02	-	-	-	-	0.09	-	0.03	0.40	-
Bromus diandrus	-	-	-	-	7.29	28.13	0.24	40.45	-	-	-	0.09	-
Bromus hordeaceus	-	0.30	0.04	-	0.39	0.62	7.52	0.61	-	0.10	-	0.04	-
Bromus rubens	-	-	-	-	-	-	-	-	-	-	-	-	-
Carduus pycnocephalus	-	-	-	-	-	-	-	-	-	-	-	0.03	-
Carthamus lanatus	-	-	-	-	-	-	-	1.16	-	-	-	-	-
Centaurium erythraea	-	-	-	-	-	-	-	-	-	-	-	-	-
Chondrilla juncea	-	-	-	-	-	-	-	-	-	-	-	-	-

Site code	WG76-1	WG76-2	WG76-3	WG76-4	WG109-1	WG109-2	WG109-3	WG109-4	MF37-1	MF37-2	MF37-3	MF37-4	MF25A-1
Cicendia quadrangularis	-	-	-	-	-	-	-	-	-	-	-	-	-
Echium plantagineum	-	-	-	-	-	-	-	-	-	-	-	-	-
Erodium botrys	-	-	-	-	-	-	-	-	0.37	-	-	-	-
Erodium cicutarium	-	-	-	-	0.02	-	-	0.02	-	-	-	-	-
Galium divaricatum	-	-	0.02	-	-	-	-	-	-	0.56	0.09	2.63	0.08
Galium murale	-	-	-	-	-	-	-	-	-	-	-	-	-
Gamochaeta americana	-	-	-	-	-	-	-	-	-	-	-	-	-
Gypsophila tubulosa	-	-	-	-	-	-	-	-	-	-	-	-	-
Hordeum sp.	-	-	-	-	14.11	-	-	31.80	-	-	-	-	-
Hypericum perforatum	-	-	-	-	-	-	-	-	-	-	-	-	-
Hypochaeris glabra	-	0.40	0.04	0.23	0.06	2.10	0.49	0.35	1.15	-	0.28	4.61	0.81
Hypochaeris radicata	-	-	-	-	0.29	-	-	0.96	12.57	1.54	0.82	0.56	0.42
Lactuca serriola	-	-	-	-	-	8.29	-	0.29	-	-	-	-	-
Linaria arvensis	-	-	-	-	-	-	-	-	-	-	-	-	-
Linaria pelisseriana	-	0.53	-	-	-	-	-	-	0.09	-	-	1.19	-
Linum trigynum	-	-	-	-	-	-	-	-	-	-	-	-	0.03
Logfia gallica	-	-	-	-	-	-	-	-	-	-	-	-	0.34
Lolium spp.	-	0.90	-	-	49.94	44.66	32.31	19.30	1.44	-	1.80	9.45	-
Modiola caroliniana	-	-	-	-	-	-	-	-	-	-	-	-	-
Moenchia erecta	-	-	-	-	-	-	-	-	-	-	-	-	-
Myosotis discolor	-	-	-	-	-	-	-	-	-	-	-	-	-
Nassella trichotoma	-	-	2.60	-	-	-	-	-	-	-	-	-	0.92
Paronychia brasiliana	-	-	-	-	-	-	-	1.71	-	-	-	-	-
Paspalum dilatatum	-	-	-	-	-	-	-	-	-	-	-	-	-
Petrorhagia nanteuilii	0.05	0.06	0.02	0.01	-	-	-	-	0.03	-	-	1.16	-
Phalaris aquatica	-	-	-	-	-	-	345	466	-	-	-	-	12.79
Plantago coronopus	-	-	-	-	-	-	-	-	-	-	-	-	-
Plantago lanceolata	-	-	-	-	-	-	-	-	-	-	-	-	-
Poa bulbosa	-	-	-	-	0.15	-	1.02	1.07	3.00	-	2.84	-	0.28
Romulea rosea	-	-	-	-	-	-	-	-	-	-	-	-	-
Rosa rubiginosa	-	-	-	-	-	-	-	-	-	-	-	-	-
Salvia verbenaca	-	-	-	-	-	-	-	-	-	-	-	-	-
Sherardia arvensis	-	-	-	-	-	-	-	-	-	-	-	-	-
Silene gallica	-	-	-	-	-	-	-	-	-	-	-	-	-
Sisymbrium officinale	-	-	-	-	-	-	-	-	-	-	-	0.13	-
Soliva sessilis	-	-	-	-	-	-	-	-	-	-	-	-	-
Tolpis barbata	-	-	-	-	-	-	-	-	1.43	0.04	0.13	0.81	0.96
Trifolium angustifolium	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifolium arvense	0.04	0.29	0.02	-	-	-	-	-	0.32	0.12	1.18	-	-
Trifolium campestre	-	-	-	-	-	-	-	-	-	-	-	-	-
Trifolium dubium	-	0.08	5.93	-	-	-	0.25	-	-	1.72	-	0.03	-
Trifolium glomeratum	-	0.03	-	0.02	-	-	0.25	-	18.09	11.66	0.28	1.42	-
Trifolium striatum	-	-	-	-	-	-	-	-	18.56	30.43	-	-	-
Trifolium subterraneum	-	0.19	-	-	7.09	1.03	3.65	0.14	31.78	12.47	9.04	0.14	8.15
Vulpia spp.	-	0.30	0.21	0.78	2.51	2.25	1.50	0.05	0.24	0.36	0.02	3.32	-

Site code	MF25A-2	MF25A-3	MF25A-4	MF11A-1	MF11A-2	MF11A-3	MF11A-4	WG148-1	WG148-2	WG148-3	WG148-4
Floristic group	2	2	2	4	4	4	3	2	2	2	2
a) Ground cover attributes											
Total biomass kgha^{-1}	450	377	404	514	514	598	1049	661	690	586	608
Live plant basal area %	10.0	5.0	7.5	7.5	10.0	12.5	10.0	15.0	14.2	10.0	17.5
Litter %	70.0	70.0	66.7	70.0	77.5	68.3	79.2	63.3	74.2	65.8	70.0
Litter depth where present (mm)	13.3	14.9	11.0	9.5	7.2	10.0	8.7	9.3	11.3	7.5	8.4
Bare ground %	15.8	19.2	22.5	11.7	10.0	5.0	10.8	8.3	7.5	15.8	6.7
Fallen log %	0.8	-	-	-	-	5.0	-	1.7	1.7	2.5	1.7
Cryptogam %	3.3	5.8	3.3	8.3	2.5	8.3	-	7.5	1.7	3.3	3.3
Rock %	-	-	-	2.5	-	0.8	-	4.2	0.8	2.5	0.8
b) Soil attributes (0 - 10 cm)											
Nitrate-N (mgkg^{-1})	<0.25	<0.25	<0.25	1.6	0.6	1.1	0.5	1.4	1.1	3.3	2.4
Carbon (%)	3.2	2.2	2.0	3.1	3.1	3.8	3.3	2.9	2.7	2.3	2.9
Nitrogen (%)	0.2	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.2

Site code	MF25A-2	MF25A-3	MF25A-4	MF11A-1	MF11A-2	MF11A-3	MF11A-4	WG148-1	WG148-2	WG148-3	WG148-4
Electrical conductivity (dSm^{-1})	0.1	0.1	0.1	<0.05	<0.05	0.1	0.1	<0.05	<0.05	0.1	<0.05
pH(CaCl2)	4.1	4.2	4.2	4.6	4.6	4.6	4.4	4.6	4.4	4.5	4.7
pH(water)	4.9	5.0	5.1	5.4	5.4	5.3	5.2	5.4	5.2	5.3	5.5
Available phosphorous (mgkg^{-1})	<4	<4	5.0	16.0	10.0	9.0	6.0	9.0	7.0	8.0	7.0
c) Native plant species (kg ha^{-1})											
Acacia dealbata	13.10	-	-	-	-	-	-	-	-	-	-
Acacia gunnii	-	-	-	-	-	-	-	-	-	-	-
Acacia parramattensis	-	-	-	-	-	-	-	-	-	-	-
Acaena ovina	-	-	0.08	0.41	0.04	19.70	3.74	-	0.43	-	17.04
Alternanthera sp. *A*	-	-	-	-	0.11	-	0.14	-	-	-	-
Aristida ramosa	102.14	29.27	98.07	0.96	-	-	1.33	45.10	48.13	1.76	12.97
Arthropodium minus	-	0.16	0.67	0.03	-	-	-	-	-	-	-
Asperula conferta	-	-	-	-	-	-	0.40	-	-	-	-
Astroloma humifusum	-	-	-	-	-	-	-	-	-	-	-
Austrodanthonia spp.	82.55	262	194	126	82.89	87.37	27.30	115	50.13	87.34	110
Austrostipa bigeniculata	-	-	-	-	-	-	-	-	-	-	-
Austrostipa densiflora	-	-	-	-	-	-	-	282	363	231	54.76
Austrostipa scabra	-	-	0.85	21.31	21.05	13.92	-	11.77	2.61	46.47	70.16
Bossiaea buxifolia	-	-	-	-	8.70	-	0.24	-	-	-	-
Bossiaea prostrata	-	-	-	0.09	-	6.48	-	-	-	-	-
Bothriochloa macra	8.95	0.08	-	10.21	-	-	0.44	27.99	114.62	53.46	66.09
Brachyloma daphnoides	-	-	-	-	-	-	-	-	-	-	-
Bulbine bulbosa	-	-	-	0.29	-	0.28	1.37	-	-	-	-
Carex inversa	2.38	0.58	-	0.16	-	-	-	0.31	0.18	0.33	0.54
Chamaesyce drummondii	-	0.08	-	0.86	-	0.09	-	-	-	-	-
Cheilanthes spp.	-	0.87	0.32	-	-	-	-	0.12	4.87	1.88	0.40
Chloris truncata	0.29	9.52	0.26	-	-	-	-	-	0.37	-	-
Chrysocephalum apiculatum	-	-	-	-	-	-	-	-	-	-	-
Chrysocephalum semipapposum	-	-	-	-	-	-	-	-	-	-	-
Convolvulus angustissimus	-	-	-	-	-	-	-	-	-	-	0.23
Cotula australis	-	-	-	-	-	-	-	-	-	-	0.04
Craspedia variabilis	-	-	-	-	-	-	0.42	-	-	-	-
Crassula sieberiana	-	-	-	-	-	-	-	0.14	-	-	-
Cymbonotus spp.	-	-	-	0.46	0.31	-	-	-	-	-	-
Cynodon dactylon	-	-	-	-	-	-	-	-	-	-	-
Cynoglossum suaveolens	-	-	-	-	-	-	-	-	-	-	-
Daucus glochidiatus	0.03	-	0.03	0.12	0.40	0.31	0.49	-	-	-	-
Daviesia genistifolia	-	-	19.80	-	-	-	-	-	-	-	-
Desmodium varians	-	-	-	-	-	0.12	-	1.32	0.10	0.23	0.28
Dianella revoluta	-	-	-	-	-	-	-	-	-	-	-
Dichelachne spp.	-	-	-	0.43	-	-	-	-	-	-	-
Dichopogon fimbriatus	-	-	-	-	-	3.66	0.13	-	-	-	-
Dillwynia sericea	11.97	-	-	-	-	-	-	-	-	-	-
Diuris sulphurea	-	-	-	-	-	-	-	-	-	-	-
Drosera peltata	-	-	-	-	-	-	-	-	-	-	-
Einadia nutans	-	-	-	-	-	-	-	-	-	11.96	-
Eleocharis acuta	-	-	-	-	-	-	-	-	-	-	-
Elymus scaber	3.19	12.38	7.16	4.51	6.78	4.08	3.35	3.62	3.30	4.16	1.51
Enneapogon nigricans	-	-	-	36.87	0.92	16.99	-	-	-	-	0.11
Eragrostis brownii	-	1.38	0.85	-	-	-	-	-	-	-	-
Erodium crinitum	-	-	-	-	-	-	-	-	-	-	-
Eryngium rostratum	-	-	-	-	-	-	-	-	-	-	-
Euchiton gymnocephalus	-	-	-	-	-	-	-	-	-	0.55	-
Euchiton sphaericus	-	-	-	-	-	-	-	-	-	0.04	-
Galium gaudichaudii	-	-	-	-	-	-	-	-	-	-	-
Geranium solanderi	-	-	-	0.04	0.09	6.04	1.60	0.06	-	-	-
Glycine spp.	-	-	-	-	-	-	-	-	-	-	-
Gonocarpus tetragynus	5.35	-	7.05	0.12	1.01	-	0.52	-	1.18	0.12	-
Goodenia hederacea	2.40	0.30	0.08	-	1.77	-	3.15	-	-	-	-
Goodenia pinnatifida	-	-	-	-	-	-	-	-	-	-	-
Haloragis heterophylla	0.81	0.99	1.09	-	0.04	-	0.49	-	-	-	0.03
Hibbertia obtusifolia	-	-	-	-	-	-	-	-	-	-	-
Hovea heterophylla	-	-	-	-	-	-	-	-	-	-	-
Hydrocotyle laxiflora	6.91	0.07	0.27	8.07	3.76	9.60	4.91	-	-	-	-
Hypericum gramineum	0.09	-	1.23	0.41	1.32	11.14	0.04	-	-	-	-
Isoetopsis graminifolia	-	-	-	-	-	-	-	-	-	-	-
Joycea pallida	-	-	15.23	2.46	-	-	518	-	-	-	-
Juncus subgen. *Genuini*	15.00	0.62	2.87	1.14	0.43	-	0.59	0.18	0.59	-	-
Leptorhynchos squamatus	-	-	-	4.49	30.10	-	0.09	0.39	-	-	1.17

Site code	MF25A-2	MF25A-3	MF25A-4	MF11A-1	MF11A-2	MF11A-3	MF11A-4	WG148-1	WG148-2	WG148-3	WG148-4
Lissanthe strigosa	-	-	-	-	-	-	-	-	-	-	-
Lomandra filiformis	43.66	-	10.52	22.52	27.17	20.86	48.61	26.95	43.11	1.89	39.28
Lomandra multiflora	-	-	-	4.72	4.87	0.36	13.98	-	-	-	-
Luzula spp.	-	-	-	-	-	-	-	-	-	-	-
Lythrum hyssopifolia	-	-	-	-	-	-	-	-	-	-	-
Melichrus urceolatus	-	-	-	-	-	-	-	-	-	-	-
Mentha diemenica	-	-	-	-	-	-	0.11	-	-	-	-
Microlaena stipoides	10.08	3.44	-	-	-	15.08	-	0.27	-	-	3.14
Microseris lanceolata	-	-	-	-	-	-	-	-	-	-	-
Opercularia hispida	-	-	-	-	-	-	-	-	-	-	-
Oxalis perennans	1.14	0.28	0.10	-	0.28	-	0.38	0.04	-	-	-
Panicum effusum	3.30	13.58	1.04	4.82	0.06	-	-	0.42	4.40	-	1.33
Pimelea curviflora	-	-	-	-	-	-	-	-	-	-	-
Pimelea linifolia	-	-	-	-	-	-	-	-	-	-	-
Plantago gaudichaudii	-	-	-	-	-	-	-	-	-	-	-
Plantago varia	-	-	-	-	-	-	-	-	-	-	-
Poa sieberiana	11.74	-	3.14	5.99	3.21	5.46	-	1.30	-	-	1.98
Pultenaea procumbens	-	-	-	-	-	-	-	-	-	-	-
Ranunculus sessiliflorus	-	-	-	-	-	-	-	-	-	-	-
Rumex brownii	-	-	-	1.03	-	0.19	0.28	-	-	-	-
Schoenus apogon	-	-	-	-	-	0.05	-	-	-	-	-
Scleranthus biflorus	-	-	-	-	-	-	-	-	-	-	-
Senecio hispidulus	-	-	-	-	-	-	-	-	-	-	-
Senecio quadridentatus	-	-	-	-	-	-	-	-	-	-	-
Solenogyne dominii	22.85	7.79	0.31	-	-	-	0.81	0.28	0.49	2.14	0.94
Stackhousia monogyna	-	-	-	-	-	-	-	-	-	-	-
Stuartina muelleri	-	-	-	0.03	-	-	-	-	-	0.06	-
Stylidium graminifolium	-	-	-	-	-	-	-	-	-	-	-
Thelymitra sp.	-	-	-	-	-	-	-	-	-	-	-
Themeda australis	24.36	-	10.21	185	284	338	387	89.27	12.42	48.56	72.82
Thysanotus patersonii	-	-	-	-	-	-	-	-	-	-	-
Tricoryne elatior	8.20	0.85	6.09	5.32	4.34	7.39	16.40	7.97	6.42	5.14	16.42
Triptilodiscus pygmaeus	5.72	0.43	0.03	1.18	0.96	0.24	0.37	0.44	0.67	0.12	-
Viola betonicifolia	-	-	-	-	-	-	-	-	-	-	-
Vittadinia cuneata	-	-	-	-	-	-	-	-	-	-	-
Vittadinia muelleri	-	1.01	-	1.21	-	11.18	-	-	-	-	-
Wahlenbergia spp.	0.07	0.37	1.23	-	0.28	-	-	-	-	0.27	-
Wurmbea dioica	-	-	-	0.36	-	-	-	-	-	0.05	0.60
d) Exotic plant species (kg ha^{-1})											
Acetosella vulgaris	-	-	-	11.53	-	-	-	-	-	-	-
Aira spp.	0.19	0.15	0.21	0.31	0.65	0.36	0.84	1.00	0.63	0.41	0.30
Anagallis arvensis	5.26	-	-	-	-	0.06	-	0.65	-	-	-
Aphanes arvensis	-	-	-	-	-	-	-	-	-	-	-
Arctotheca calendula	-	0.27	-	-	-	-	-	-	0.05	-	-
Briza maxima	0.03	-	-	-	-	0.42	-	3.64	-	-	1.73
Briza minor	0.03	-	-	-	0.56	0.34	0.13	-	0.18	-	0.40
Bromus diandrus	1.86	-	-	-	-	-	-	-	-	-	-
Bromus hordeaceus	0.12	-	-	1.09	0.12	1.20	-	1.20	17.55	1.73	1.71
Bromus rubens	-	-	-	12.91	-	-	-	0.10	-	0.04	3.74
Carduus pycnocephalus	-	-	-	-	-	-	-	-	-	-	-
Carthamus lanatus	-	-	-	-	-	-	-	-	-	-	18.64
Centaurium erythraea	-	-	-	-	-	-	-	-	-	-	-
Chondrilla juncea	-	-	-	-	-	0.09	-	-	-	4.34	0.11
Cicendia quadrangularis	-	-	-	-	-	-	-	-	-	-	-
Echium plantagineum	-	-	-	-	-	-	-	-	-	-	-
Erodium botrys	-	-	-	-	-	-	-	-	-	-	-
Erodium cicutarium	-	-	-	1.56	-	0.09	0.32	-	-	0.08	0.66
Galium divaricatum	-	-	-	0.42	0.06	0.17	0.24	-	-	-	-
Galium murale	-	-	-	-	-	0.05	-	-	-	-	-
Gamochaeta americana	-	-	-	-	-	-	-	-	-	-	-
Gypsophila tubulosa	-	-	-	0.03	-	-	-	-	-	-	-
Hordeum sp.	-	-	-	-	-	-	-	-	-	-	-
Hypericum perforatum	-	-	-	-	-	-	-	-	-	-	-
Hypochaeris glabra	0.09	-	-	0.23	0.24	0.13	0.21	2.03	5.12	39.40	7.09
Hypochaeris radicata	0.08	6.44	-	0.38	-	1.05	-	0.41	2.15	-	31.64
Lactuca serriola	-	-	-	-	-	-	-	-	-	-	-
Linaria arvensis	-	-	-	-	-	-	-	-	-	-	-
Linaria pelisseriana	-	-	-	-	-	-	-	-	-	-	-
Linum trigynum	0.03	-	-	-	-	-	-	-	-	-	-

Site code	MF25A-2	MF25A-3	MF25A-4	MF11A-1	MF11A-2	MF11A-3	MF11A-4	WG148-1	WG148-2	WG148-3	WG148-4
Logfia gallica	-	0.08	0.09	-	-	-	-	-	-	-	-
Lolium spp.	0.08	0.31	-	-	-	0.15	-	17.80	-	0.25	8.72
Modiola caroliniana	-	-	-	-	-	-	-	-	-	-	-
Moenchia erecta	-	-	-	-	-	-	-	-	-	-	-
Myosotis discolor	-	-	-	0.38	-	-	-	-	-	-	-
Nassella trichotoma	-	-	-	-	-	-	-	-	-	-	-
Paronychia brasiliana	-	-	-	-	-	-	-	-	-	-	-
Paspalum dilatatum	-	-	-	-	-	-	-	-	-	-	-
Petrorhagia nanteuilii	-	-	-	1.25	0.11	2.91	-	-	0.07	0.03	-
Phalaris aquatica	33.53	-	-	-	-	-	-	-	-	-	-
Plantago coronopus	-	-	-	-	-	-	-	-	-	-	-
Plantago lanceolata	-	-	-	0.04	-	-	-	-	-	-	-
Poa bulbosa	-	3.66	-	-	-	-	-	3.14	1.35	5.30	0.12
Romulea rosea	-	-	-	-	-	-	-	-	-	-	-
Rosa rubiginosa	-	-	-	8.20	-	-	-	-	-	-	-
Salvia verbenaca	-	-	-	-	-	-	-	0.69	-	-	16.86
Sherardia arvensis	-	-	-	6.48	-	0.60	-	-	-	-	-
Silene gallica	-	-	-	-	-	-	-	-	-	-	-
Sisymbrium officinale	-	-	-	-	-	-	-	-	-	-	-
Soliva sessilis	-	-	-	-	-	-	-	-	-	-	-
Tolpis barbata	0.62	0.22	-	0.92	-	-	0.11	-	0.04	2.10	0.13
Trifolium angustifolium	-	-	-	-	-	-	-	-	-	-	-
Trifolium arvense	-	-	-	1.61	2.08	4.04	0.23	0.12	0.04	0.29	0.04
Trifolium campestre	-	-	-	-	-	-	-	0.12	-	-	-
Trifolium dubium	-	-	-	-	-	1.69	-	-	-	0.09	0.25
Trifolium glomeratum	-	-	-	-	4.25	0.06	-	1.75	1.43	-	9.54
Trifolium striatum	-	-	-	0.38	8.43	0.19	6.33	0.29	0.04	10.73	0.37
Trifolium subterraneum	-	-	0.02	12.28	2.41	5.07	0.04	9.42	0.57	19.96	32.29
Vulpia spp.	-	0.03	8.40	1.96	9.04	0.90	1.64	0.46	0.04	0.98	0.40

Site code	MF38-1	MF38-2	MF38-3	MF38-4	WG152-1	WG152-2	WG152-3	WG152-4	MF9A-1	MF9A-2
Floristic group	5	2	3	2	6	6	6	1	4	4
a) Ground cover attributes										
Total biomass kgha^{-1}	597	267	1101	204	314	346	304	650	243	258
Live plant basal area %	7.5	12.5	5.8	3.3	6.7	10.0	15.8	19.2	19.2	15.0
Litter %	66.7	66.7	77.5	79.2	75.0	74.2	62.5	71.7	23.3	26.7
Litter depth where present (mm)	12.9	12.6	18.0	18.4	6.0	5.7	4.2	7.3	13.5	22.2
Bare ground %	18.3	18.3	15.0	14.2	17.5	12.5	10.8	7.5	27.5	20.8
Fallen log %	2.5	2.5	0.8	-	-	-	2.5	1.7	1.7	1.7
Cryptogam %	5.0	-	0.8	3.3	0.8	2.5	6.7	-	26.7	32.5
Rock %	-	-	-	-	-	0.8	1.7	-	1.7	3.3
b) Soil attributes (0 - 10 cm)										
Nitrate-N (mgkg^{-1})	0.3	0.5	0.3	0.4	8.6	8.3	5.2	6.8	0.5	0.7
Carbon (%)	2.8	3.4	3.9	3.0	2.0	2.0	1.9	2.6	2.5	2.5
Nitrogen (%)	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Electrical conductivity (dSm^{-1})	0.1	0.1	<0.05	0.1	0.1	0.1	<0.05	0.1	<0.05	<0.05
pH(CaCl2)	4.2	4.5	4.1	4.3	4.4	4.4	4.4	4.8	4.5	4.5
pH(water)	5.0	5.3	4.9	5.0	5.2	5.2	5.3	5.6	5.3	5.3
Available phosphorous (mgkg^{-1})	6.0	5.0	5.0	8.0	7.0	7.0	7.0	9.0	8.0	7.0
c) Native plant species (kg ha^{-1})										
Acacia dealbata	-	-	-	-	-	-	-	-	-	-
Acacia gunnii	-	-	2.08	-	-	-	-	-	0.28	-
Acacia parramattensis	-	-	-	-	-	-	-	-	-	-
Acaena ovina	1.48	-	-	5.44	-	-	-	-	9.88	-
Alternanthera sp. *A*	-	-	-	-	-	-	0.02	-	-	-
Aristida ramosa	6.81	16.34	11.47	7.56	6.92	-	-	-	7.63	19.04
Arthropodium minus	-	-	-	-	-	0.05	-	-	-	-
Asperula conferta	-	-	-	-	-	-	-	-	-	-
Astroloma humifusum	-	-	-	-	-	-	-	-	-	-
Austrodanthonia spp.	64.34	73.90	40.09	63.89	146	174	80.00	60.03	34.17	61.88
Austrostipa bigeniculata	-	-	-	-	-	-	-	-	-	-
Austrostipa densiflora	-	-	-	-	11.38	6.98	-	-	-	11.43

Site code	MF38-1	MF38-2	MF38-3	MF38-4	WG152-1	WG152-2	WG152-3	WG152-4	MF9A-1	MF9A-2
Austrastipa scabra	1.56	7.39	4.19	0.56	24.64	28.87	12.53	22.55	40.11	17.77
Bossiaea buxifolia	-	-	-	-	-	-	-	-	1.04	-
Bossiaea prostrata	-	-	0.82	-	-	-	-	-	-	-
Bathriochloa macra	-	-	-	7.41	-	-	6.86	0.08	-	8.90
Brachyloma daphnoides	-	-	-	-	-	-	-	-	-	-
Bulbine bulbosa	-	0.07	-	-	-	-	-	-	-	-
Carex inversa	0.60	0.14	-	5.93	-	-	-	0.34	-	-
Chamaesyce drummondii	-	-	-	-	0.18	1.48	0.05	-	0.14	0.13
Cheilanthes spp.	-	-	-	-	-	-	0.53	-	-	0.14
Chloris truncata	-	-	-	-	21.10	4.06	9.78	-	-	-
Chrysacephalum apiculatum	-	-	-	-	-	-	-	-	-	-
Chrysocephalum semipapposum	-	-	-	-	-	-	-	-	-	-
Convolvulus angustissimus	-	-	-	-	-	-	5.24	-	0.06	-
Cotula australis	-	-	-	-	0.02	-	-	-	-	-
Craspedia variabilis	-	-	-	-	-	-	-	-	-	-
Crassula sieberiana	-	-	-	-	0.13	0.04	-	0.03	0.03	-
Cymbonotus spp.	-	-	-	0.49	-	-	-	-	-	-
Cynodon dactylon	-	-	-	-	-	-	-	-	-	-
Cynoglossum suaveolens	-	-	-	-	-	-	-	-	-	-
Daucus glochidiatus	-	0.34	-	0.05	-	-	-	-	0.04	0.17
Daviesia genistifolia	237	-	-	-	-	-	-	-	-	-
Desmodium varians	-	1.13	-	-	-	-	0.16	-	-	3.52
Dianella revoluta	-	8.67	-	-	-	-	-	-	-	-
Dichelachne spp.	-	-	-	-	-	-	-	-	-	-
Dichopogan fimbriatus	-	-	-	-	-	-	-	-	-	-
Dillwynia sericea	2.25	-	4.55	-	-	-	-	-	-	-
Diuris sulphurea	-	-	-	-	-	-	-	-	-	-
Drosera peltata	-	-	-	-	-	-	-	-	-	-
Einadia nutans	-	-	-	-	-	-	-	-	-	-
Eleocharis acuta	-	-	-	-	-	-	-	3.82	-	-
Elymus scaber	1.45	0.60	0.53	2.25	3.99	5.13	13.56	1.82	0.98	7.68
Enneapogon nigricans	-	-	-	-	-	-	-	-	20.75	8.65
Eragrostis brownii	-	-	-	-	0.45	-	0.03	-	-	-
Erodium crinitum	-	-	-	-	-	-	-	-	-	-
Eryngium rostratum	-	-	-	-	-	-	-	-	-	-
Euchitan gymnocephalus	-	-	0.17	0.05	-	-	-	-	-	-
Euchiton sphaericus	-	-	-	-	-	-	-	-	-	-
Galium gaudichaudii	-	-	-	-	-	-	-	-	-	-
Geranium salanderi	-	0.05	-	-	-	-	-	0.12	-	-
Glycine spp.	-	-	-	-	-	-	0.75	-	-	-
Gonocarpus tetragynus	14.34	7.04	5.45	18.41	0.06	-	-	0.11	1.50	3.47
Goodenia hederacea	0.59	-	9.47	1.98	-	-	-	-	0.25	6.92
Goodenia pinnatifida	-	-	-	-	-	-	0.67	-	-	-
Haloragis heterophylla	0.20	0.02	0.16	0.09	-	-	-	-	-	-
Hibbertia abtusifolia	0.31	-	-	-	-	-	-	-	-	-
Hovea heterophylla	-	-	-	-	-	-	-	-	-	-
Hydrocotyle laxiflora	2.03	9.62	0.89	2.48	-	-	-	-	0.01	4.30
Hypericum gramineum	1.42	3.89	-	2.68	-	-	-	-	-	-
Isoetopsis graminifolia	-	-	-	-	-	-	-	-	-	-
Joycea pallida	193	3.71	930	6.13	-	-	-	-	-	-
Juncus subgen. *Genuini*	1.51	-	7.41	-	0.02	-	-	-	-	-
Leptorhynchos squamatus	-	0.67	-	0.11	-	-	-	-	-	-
Lissanthe strigosa	15.14	-	6.79	-	-	-	-	-	-	-
Lomandra filiformis	21.37	17.25	17.98	38.62	-	2.08	0.60	-	6.16	8.74
Lomandra multiflora	-	6.18	6.15	-	-	-	-	-	-	-
Luzula spp.	0.11	-	0.03	-	-	-	-	-	0.03	-
Lythrum hyssapifolia	-	-	-	-	-	-	-	-	-	-
Melichrus urceolatus	-	51.38	-	-	-	-	-	-	13.17	5.44
Mentha diemenica	-	-	-	-	-	-	-	-	-	-
Microlaena stipoides	1.27	7.41	1.84	-	3.19	2.57	-	29.93	-	6.92
Microseris lanceolata	-	-	-	-	-	-	-	-	-	-
Opercularia hispida	-	-	0.62	-	-	-	-	-	-	-
Oxalis perennans	-	-	0.19	0.13	-	0.58	0.06	0.04	-	-
Panicum effusum	-	0.51	-	-	24.47	3.47	43.52	7.16	2.00	0.23
Pimelea curviflora	-	-	-	-	-	-	-	-	-	-
Pimelea linifolia	-	-	-	-	-	-	-	-	-	-
Plantago gaudichaudii	-	-	-	-	-	-	-	-	-	-
Plantago varia	-	-	-	-	-	-	-	-	-	-
Poa sieberiana	7.03	11.03	11.50	8.74	-	-	2.67	-	-	0.01
Pultenaea procumbens	-	-	-	-	-	-	-	-	-	-

Site code	MF38-1	MF38-2	MF38-3	MF38-4	WG152-1	WG152-2	WG152-3	WG152-4	MF9A-1	MF9A-2
Ranunculus sessiliflorus	-	-	-	-	-	-	-	-	-	-
Rumex brownii	-	-	-	-	-	-	-	1.15	-	-
Schoenus apogon	0.29	-	-	-	-	-	-	-	-	-
Scleranthus biflorus	-	-	-	-	-	-	-	-	-	-
Senecio hispidulus	-	-	-	-	-	-	-	-	-	-
Senecio quadridentatus	8.29	-	-	-	-	-	-	-	-	-
Solenogyne dominii	0.04	1.94	0.34	5.62	-	0.17	-	-	-	3.52
Stackhousia monogyna	-	-	-	-	-	-	-	-	-	-
Stuartina muelleri	-	-	-	-	-	-	-	-	-	-
Stylidium graminifolium	-	-	-	-	-	-	-	-	-	-
Thelymitra sp.	-	-	-	-	-	-	-	-	-	-
Themeda australis	6.92	30.26	7.82	8.23	0.06	0.56	8.89	-	48.16	50.42
Thysanotus patersonii	-	-	-	-	-	-	-	-	-	-
Tricoryne elatior	-	-	-	-	-	-	-	-	-	-
Triptilodiscus pygmaeus	0.70	0.15	-	-	-	-	-	-	0.04	0.90
Viola betonicifolia	-	-	-	-	-	-	-	-	-	-
Vittadinia cuneata	0.47	-	-	0.67	-	-	-	-	-	-
Vittadinia muelleri	-	-	-	1.92	-	-	0.20	-	6.45	13.54
Wahlenbergia spp.	-	0.13	2.68	0.95	-	-	-	-	3.47	-
Wurmbea dioica	0.04	0.02	-	0.15	-	-	-	-	0.20	-
d) Exotic plant species (kg ha^{-1})										
Acetosella vulgaris	-	-	-	-	0.19	0.02	0.20	0.87	0.08	-
Aira spp.	0.07	0.24	0.02	0.39	1.37	0.67	2.21	1.18	1.35	1.02
Anagallis arvensis	-	-	-	-	-	-	-	-	-	-
Aphanes arvensis	-	-	-	-	-	-	-	-	-	-
Arctotheca calendula	-	-	-	-	0.29	0.66	-	0.03	-	-
Briza maxima	0.20	0.48	-	-	-	0.10	-	-	4.24	0.82
Briza minor	0.02	0.83	0.05	-	-	-	-	-	0.97	-
Bromus diandrus	-	-	-	-	0.05	-	-	4.01	-	-
Bromus hordeaceus	-	0.05	-	-	1.21	0.63	0.08	2.98	0.29	-
Bromus rubens	-	-	-	-	-	-	-	-	-	-
Carduus pycnocephalus	-	-	-	-	-	-	-	-	-	-
Carthamus lanatus	-	-	-	-	-	-	-	-	-	-
Centaurium erythraea	-	-	-	-	-	-	-	-	-	-
Chondrilla juncea	-	-	-	-	-	-	-	0.33	-	-
Cicendia quadrangularis	-	-	-	-	-	-	-	-	-	-
Echium plantagineum	-	-	-	-	-	-	-	-	-	-
Erodium botrys	-	-	-	-	-	1.39	-	0.90	-	-
Erodium cicutarium	-	-	-	-	0.02	-	-	-	-	0.38
Galium divaricatum	-	0.02	-	-	-	-	-	-	0.15	0.08
Galium murale	-	-	-	-	-	-	-	-	-	-
Gamochaeta americana	-	-	-	-	-	-	-	-	-	-
Gypsophila tubulosa	-	-	-	-	-	-	-	-	1.51	0.15
Hordeum sp.	-	-	-	-	-	-	-	-	-	-
Hypericum perforatum	-	-	-	-	-	-	-	-	-	-
Hypochaeris glabra	0.19	2.47	0.02	0.60	2.15	9.28	4.44	3.21	20.05	3.63
Hypochaeris radicata	-	-	-	-	-	0.02	-	9.14	-	-
Lactuca serriola	-	-	-	-	-	-	-	-	-	-
Linaria arvensis	-	-	-	-	-	-	-	-	-	-
Linaria pelisseriana	-	-	-	-	-	-	-	-	-	-
Linum trigynum	-	-	-	-	-	-	-	-	-	-
Logfia gallica	-	-	-	-	0.31	-	6.97	-	-	-
Lolium spp.	-	-	-	-	10.51	12.41	0.02	5.73	-	4.47
Modiola caroliniana	-	-	-	-	-	-	-	-	-	-
Moenchia erecta	-	-	-	-	-	-	-	0.07	-	-
Myosotis discolor	-	-	-	-	-	-	-	-	-	-
Nassella trichotoma	-	-	-	-	-	-	-	0.26	-	-
Paronychia brasiliana	-	-	-	-	-	-	-	0.20	-	-
Paspalum dilatatum	-	-	-	-	-	-	-	-	-	-
Petrorhagia nanteuilii	-	0.16	-	-	-	-	-	-	2.23	0.85
Phalaris aquatica	-	-	-	-	18.16	23.48	13.64	394	-	-
Plantago coronopus	-	-	-	-	-	-	-	-	-	-
Plantago lanceolata	-	-	-	-	-	-	-	-	-	-
Poa bulbosa	-	-	-	0.45	-	-	-	0.11	-	-
Romulea rosea	-	-	-	-	-	-	-	-	-	-
Rosa rubiginosa	-	-	-	-	-	-	-	-	-	-
Salvia verbenaca	-	-	-	-	-	-	-	-	-	-
Sherardia arvensis	-	-	-	-	-	-	-	-	-	-
Silene gallica	-	-	-	-	-	-	0.02	-	-	-

Site code	MF38-1	MF38-2	MF38-3	MF38-4	WG152-1	WG152-2	WG152-3	WG152-4	MF9A-1	MF9A-2
Sisymbrium officinale	-	-	-	-	-	-	-	-	-	-
Soliva sessilis	-	-	-	-	-	-	-	-	-	-
Tolpis barbata	-	-	-	-	-	-	-	-	0.04	0.44
Trifolium angustifolium	-	-	-	-	-	-	-	-	0.04	-
Trifolium arvense	-	0.94	-	-	0.62	0.34	0.19	1.06	3.46	1.50
Trifolium campestre	-	-	-	-	0.14	0.03	0.26	0.52	-	-
Trifolium dubium	-	-	-	-	0.02	-	0.12	0.49	-	-
Trifolium glomeratum	-	-	-	-	0.05	0.27	0.62	5.92	2.39	-
Trifolium striatum	-	-	-	0.02	0.93	3.70	5.03	47.66	0.22	0.05
Trifolium subterraneum	-	0.47	-	0.02	33.99	60.38	83.97	34.11	2.09	-
Vulpia spp.	0.42	0.73	0.09	0.45	1.17	1.24	0.31	3.85	2.26	0.75

Site code	MF9A-3	MF9A-4	MF22AZ-1	MF 22AZ-2	MF22AZ-3	MF22AZ-4	WG63A-1	WG63A-2	WG63A-3	WG63A-4
Floristic group	4	2	2	3	3	2	2	2	2	4
a) Ground cover attributes										
Total biomass kgha^{-1}	236	262	704	2276	2123	384	355	452	429	432
Live plant basal area %	15.8	16.7	14.2	22.5	26.7	19.2	19.2	21.7	13.3	19.2
Litter %	57.5	58.3	30.8	28.3	24.2	35.0	42.5	53.3	45.8	49.2
Litter depth where present (mm)	15.3	15.2	12.7	11.4	16.9	10.3	4.0	4.1	4.3	5.0
Bare ground %	10.8	11.7	25.8	27.5	20.8	32.5	19.2	20.8	27.5	16.7
Fallen log %	-	1.7	1.7	-	-	-	1.7	-	-	5.0
Cryptogam %	13.3	11.7	27.5	21.7	28.3	13.3	17.5	2.5	7.5	6.7
Rock %	2.5	-	-	-	-	-	-	1.7	5.8	3.3
b) Soil attributes (0 - 10 cm)										
Nitrate-N (mgkg^{-1})	2.2	4.5	<0.25	<0.25	<0.25	<0.25	0.4	<0.25	<0.25	0.4
Carbon (%)	3.6	4.4	2.6	2.1	2.6	2.4	1.7	1.8	1.8	2.3
Nitrogen (%)	0.2	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Electrical conductivity (dSm^{-1})	0.1	0.1	0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
pH(CaCl2)	4.7	4.5	4.0	4.0	4.0	4.1	4.6	4.7	4.7	4.9
pH(water)	5.5	5.2	4.8	4.8	4.7	4.9	5.4	5.6	5.5	5.8
Available phosphorous (mgkg^{-1})	8.0	11.0	<4	6.0	<4	5.0	5.0	5.0	<4	5.0
c) Native plant species (kg ha^{-1})										
Acacia dealbata	-	-	-	-	-	-	-	-	-	-
Acacia gunnii	-	-	-	-	-	-	-	-	-	-
Acacia parramattensis	-	-	-	-	-	-	-	-	-	-
Acaena ovina	0.30	0.16	-	-	-	-	7.66	-	1.20	0.33
Alternanthera sp. A	-	-	-	-	-	-	0.48	0.23	-	-
Aristida ramosa	-	-	108	116	165	111	22.48	76.00	72.53	8.22
Arthropodium minus	-	-	-	-	-	-	-	-	-	-
Asperula conferta	-	0.04	-	-	-	-	-	1.19	0.27	0.33
Astroloma humifusum	-	-	-	-	3.15	-	-	-	-	-
Austrodanthonia spp.	67.77	89.08	354	83.21	97.67	174	201	163	106	95.41
Austrostipa bigeniculata	3.59	-	-	-	-	-	-	-	-	-
Austrostipa densiflora	-	-	-	-	-	-	-	-	-	-
Austrostipa scabra	15.49	45.92	-	0.67	-	-	3.83	12.49	0.53	2.83
Bossiaea buxifolia	-	-	-	-	-	-	-	-	-	-
Bossiaea prostrata	0.47	0.03	-	-	-	-	-	-	0.34	-
Bothriochloa macra	0.76	-	-	-	-	-	39.68	67.67	96.08	53.45
Brachyloma daphnoides	-	-	-	-	-	-	-	-	-	-
Bulbine bulbosa	-	-	-	-	-	-	-	-	-	-
Carex inversa	-	0.63	-	-	-	-	-	1.67	-	-
Chamaesyce drummondii	-	-	-	-	-	0.82	7.41	-	0.16	-
Cheilanthes spp.	-	-	-	-	-	-	-	3.57	0.40	0.09
Chloris truncata	-	-	12.93	5.42	6.38	-	11.78	4.20	0.53	-
Chrysocephalum apiculatum	-	-	-	15.61	11.80	-	-	-	-	-
Chrysocephalum semipapposum	1.04	-	-	-	-	-	-	-	-	-
Convolvulus angustissimus	-	0.03	-	-	-	-	0.06	-	-	0.16
Cotula australis	-	0.06	-	-	-	-	-	-	-	-
Craspedia variabilis	-	0.23	-	-	-	-	-	-	-	-
Crassula sieberiana	-	0.02	-	-	-	-	-	-	-	-

Site code	MF9A-3	MF9A-4	MF22AZ-1	MF 22AZ-2	MF22AZ-3	MF22AZ-4	WG63A-1	WG63A-2	WG63A-3	WG63A-4
Cymbonotus spp.	-	-	-	-	-	-	-	-	-	-
Cynodon dactylon	-	-	-	-	-	-	-	-	-	-
Cynoglossum suaveolens	-	-	-	-	-	-	-	-	-	-
Daucus glochidiatus	0.94	-	-	-	-	-	-	-	-	-
Daviesia genistifolia	-	-	5.19	10.37	-	2.52	-	-	-	-
Desmodium varians	2.24	0.47	-	-	-	-	0.34	0.03	0.73	2.52
Dianella revoluta	-	-	-	-	-	-	-	-	-	-
Dichelachne spp.	-	-	-	-	-	2.10	-	-	-	-
Dichopogon fimbriatus	-	-	-	-	-	-	-	0.04	-	-
Dillwynia sericea	-	-	-	3.72	19.06	-	-	-	-	-
Diuris sulphurea	-	-	-	-	-	-	-	-	-	-
Drosera peltata	-	-	-	-	-	-	-	-	-	-
Einadia nutans	-	-	-	-	-	-	-	-	-	-
Eleocharis acuta	-	-	-	-	-	-	-	-	-	-
Elymus scaber	11.53	8.10	2.62	2.72	3.93	0.73	4.03	1.13	0.51	0.35
Enneapogon nigricans	1.48	-	-	-	-	-	5.07	-	6.21	0.90
Eragrostis brownii	-	-	-	0.29	-	-	0.23	-	-	-
Erodium crinitum	-	-	-	-	-	-	-	-	-	-
Eryngium rostratum	-	-	-	-	-	-	-	-	-	-
Euchiton gymnocephalus	-	-	-	-	-	-	0.02	-	-	0.29
Euchiton sphaericus	-	-	-	-	-	-	-	-	-	-
Galium gaudichaudii	-	-	-	-	-	-	-	-	-	-
Geranium solanderi	0.02	6.76	-	-	-	-	-	-	-	-
Glycine spp.	5.44	-	-	-	-	-	-	-	-	0.23
Gonocarpus tetragynus	0.97	0.15	1.76	19.72	6.67	0.88	0.81	0.84	1.21	0.56
Goodenia hederacea	0.40	2.59	1.02	3.30	11.00	2.22	-	3.05	-	-
Goodenia pinnatifida	-	-	-	-	-	-	-	-	-	-
Haloragis heterophylla	-	0.13	27.71	0.21	0.30	17.89	0.21	2.31	1.38	-
Hibbertia obtusifolia	4.45	-	-	-	-	-	-	-	0.09	-
Hovea heterophylla	-	-	-	-	-	-	-	-	-	-
Hydrocotyle laxiflora	1.14	2.78	-	0.21	-	-	-	-	-	1.34
Hypericum gramineum	0.06	0.10	-	3.22	-	3.82	-	0.82	0.06	-
Isoetopsis graminifolia	-	-	-	-	-	-	-	-	-	-
Joycea pallida	-	-	63.30	1894	1746	0.08	-	-	-	-
Juncus subgen. *Genuini*	0.31	0.45	0.76	0.62	0.47	0.20	0.71	0.40	-	0.29
Leptorhynchos squamatus	-	0.23	-	-	-	-	0.03	6.11	7.48	8.69
Lissanthe strigosa	-	-	-	-	-	-	-	-	-	-
Lomandra filiformis	23.92	4.80	22.94	34.91	1.52	7.13	-	1.27	0.98	16.01
Lomandra multiflora	-	-	-	-	-	-	-	-	-	-
Luzula spp.	-	-	-	-	-	-	-	0.20	-	-
Lythrum hyssopifolia	-	-	0.28	-	-	1.08	-	-	-	-
Melichrus urceolatus	3.47	-	-	12.35	4.22	-	-	-	-	-
Mentha diemenica	-	-	-	-	-	-	-	-	-	-
Microlaena stipoides	0.34	17.78	23.39	3.68	8.36	2.52	-	-	-	-
Microseris lanceolata	-	-	-	-	-	-	-	-	-	-
Opercularia hispida	-	-	-	-	-	-	-	-	-	-
Oxalis perennans	0.30	0.02	-	-	-	-	0.89	-	-	0.19
Panicum effusum	0.02	-	10.99	1.52	3.51	9.04	3.90	7.72	-	0.26
Pimelea curviflora	-	-	-	-	-	-	-	-	2.01	-
Pimelea linifolia	-	-	-	-	0.95	-	-	-	-	-
Plantago gaudichaudii	-	-	-	-	-	-	-	-	-	-
Plantago varia	-	-	-	-	-	-	-	-	-	-
Poa sieberiana	4.28	17.40	6.50	40.64	3.77	16.37	-	-	0.48	4.68
Pultenaea procumbens	-	-	-	-	-	-	-	-	-	-
Ranunculus sessiliflorus	-	-	-	-	-	-	-	-	-	-
Rumex brownii	-	0.02	-	-	-	-	-	-	-	0.98
Schoenus apogon	-	-	-	-	0.17	-	-	-	-	-
Scleranthus biflorus	-	-	-	-	-	-	-	-	-	-
Senecio hispidulus	-	-	-	-	-	-	-	-	-	-
Senecio quadridentatus	-	-	-	-	-	-	-	-	-	-
Solenogyne dominii	0.53	-	2.19	12.16	3.70	4.89	0.29	0.71	0.03	0.02
Stackhousia monogyna	-	-	-	-	-	-	-	-	-	-
Stuartina muelleri	-	-	-	-	-	-	-	-	-	-
Stylidium graminifolium	-	-	-	1.02	-	-	-	-	-	-
Thelymitra sp.	-	-	-	-	-	-	-	-	-	-
Themeda australis	62.99	16.83	-	-	-	-	20.23	83.31	107	195
Thysanotus patersonii	-	-	-	-	-	-	-	-	-	-
Tricoryne elatior	0.58	0.02	10.04	-	0.55	-	0.91	1.30	0.41	0.05

Site code	MF9A-3	MF9A-4	MF22AZ-1	MF 22AZ-2	MF22AZ-3	MF22AZ-4	WG63A-1	WG63A-2	WG63A-3	WG63A-4
Triptilodiscus pygmaeus	0.18	-	6.19	0.20	0.20	0.38	0.07	0.62	0.27	0.26
Viola betonicifolia	-	-	-	-	-	-	-	-	-	-
Vittadinia cuneata	-	-	-	-	-	-	-	-	-	-
Vittadinia muelleri	0.69	-	-	2.22	-	-	2.54	5.78	0.62	16.35
Wahlenbergia spp.	1.38	0.13	2.91	-	0.02	-	1.61	0.25	0.03	0.06
Wurmbea dioica	0.09	0.07	-	-	-	-	-	0.03	-	0.10
d) Exotic plant species (kg ha^{-1})										
Acetosella vulgaris	-	9.89	0.27	-	-	-	-	-	-	-
Aira spp.	0.54	0.04	0.45	0.44	0.17	3.27	0.63	0.29	0.29	0.19
Anagallis arvensis	0.31	-	0.05	-	-	-	-	-	-	-
Aphanes arvensis	-	-	-	-	-	-	-	-	-	-
Arctotheca calendula	-	-	-	-	-	-	5.70	0.23	0.82	-
Briza maxima	-	0.31	6.36	-	-	-	-	-	-	-
Briza minor	-	-	0.05	-	0.02	0.06	-	0.43	0.04	0.02
Bromus diandrus	-	-	-	-	-	-	-	-	-	-
Bromus hordeaceus	0.12	0.26	-	-	-	-	-	-	0.13	-
Bromus rubens	-	-	-	-	-	-	-	-	-	-
Carduus pycnocephalus	-	-	-	-	-	-	-	-	-	-
Carthamus lanatus	-	-	-	-	-	-	-	-	-	-
Centaurium erythraea	-	-	-	-	-	-	-	-	-	-
Chondrilla juncea	-	-	-	-	-	-	-	-	-	-
Cicendia quadrangularis	-	-	-	-	-	-	-	-	-	-
Echium plantagineum	-	-	-	-	-	-	-	-	-	-
Erodium botrys	-	0.10	-	-	-	-	-	-	-	-
Erodium cicutarium	-	0.02	-	-	-	-	-	-	-	-
Galium divaricatum	0.28	-	-	-	-	0.73	-	0.04	-	0.03
Galium murale	-	-	-	-	-	-	-	-	-	-
Gamochaeta americana	-	-	-	-	-	-	-	-	-	-
Gypsophila tubulosa	-	-	-	-	-	-	-	-	-	-
Hordeum sp.	-	-	-	-	-	-	-	-	-	-
Hypericum perforatum	-	-	-	-	-	-	-	-	-	-
Hypochaeris glabra	1.07	15.41	9.07	3.89	12.58	7.06	8.66	0.22	1.45	0.38
Hypochaeris radicata	-	-	0.58	-	-	-	-	-	-	3.26
Lactuca serriola	-	-	-	-	-	-	-	-	-	-
Linaria arvensis	1.08	-	-	-	-	-	-	-	0.03	-
Linaria pelisseriana	-	-	0.05	-	0.82	-	-	0.10	-	-
Linum trigynum	-	-	-	-	-	-	-	-	-	-
Logfia gallica	-	-	0.12	-	0.10	0.03	0.08	0.03	0.08	0.02
Lolium spp.	-	4.04	-	-	-	-	-	-	-	-
Modiola caroliniana	-	-	-	-	-	-	-	-	-	-
Moenchia erecta	-	-	-	-	-	-	-	-	-	-
Myosotis discolor	-	-	-	-	-	-	-	-	-	-
Nassella trichotoma	6.92	0.04	-	-	-	-	-	-	-	-
Paronychia brasiliana	-	-	-	-	-	-	-	-	-	-
Paspalum dilatatum	-	-	-	-	-	-	-	-	-	-
Petrorhagia nanteuilii	0.07	0.84	-	-	-	-	-	-	0.24	-
Phalaris aquatica	-	2.28	8.02	-	-	-	-	-	-	-
Plantago coronopus	-	-	0.02	-	-	-	-	-	-	-
Plantago lanceolata	-	-	-	-	-	-	-	-	-	-
Poa bulbosa	-	9.40	-	-	-	-	0.50	0.03	-	-
Romulea rosea	-	-	-	-	-	-	-	-	-	-
Rosa rubiginosa	3.18	-	-	-	-	-	-	-	-	-
Salvia verbenaca	-	-	-	-	-	-	-	-	-	-
Sherardia arvensis	-	-	-	-	-	-	-	-	-	-
Silene gallica	-	-	0.71	-	-	-	-	-	-	-
Sisymbrium officinale	-	-	-	-	-	-	-	-	-	-
Soliva sessilis	-	-	-	-	-	-	-	-	-	-
Tolpis barbata	0.25	0.04	13.07	0.87	1.54	10.07	0.06	0.12	0.50	0.17
Trifolium angustifolium	-	-	-	-	-	-	1.79	2.50	17.49	10.03
Trifolium arvense	0.10	1.12	-	-	-	-	0.23	-	-	-
Trifolium campestre	-	-	-	-	-	0.24	-	-	0.44	0.19
Trifolium dubium	0.05	0.02	-	-	-	-	-	-	-	-
Trifolium glomeratum	0.10	1.02	-	-	-	-	-	-	-	-
Trifolium striatum	0.22	0.15	0.07	-	0.02	0.43	0.46	1.94	-	7.11
Trifolium subterraneum	-	1.60	1.97	-	0.07	4.34	-	-	0.09	-
Vulpia spp.	0.16	0.06	0.08	-	0.02	0.03	0.13	0.03	0.10	0.03

Native vegetation of southeast NSW: a revised classification and map for the coast and eastern tablelands

M.G. Tozer, K. Turner, D.A. Keith, D. Tindall[#], C. Pennay[#], C.Simpson, B. MacKenzie, P. Beukers and S. Cox

NSW Department of Environment & Climate Change, Scientific Sevices Division
PO Box 1967 Hurstville 2220 AUSTRALIA
[#]Present address: Qld Department of Natural Resources & Water, Qscape Building, 80 Meiers Rd Indooroopilly 4068

Abstract: Native vegetation of the NSW south coast, escarpment and southeast tablelands was classified into 191 floristic assemblages at a level of detail appropriate for the discrimination of Threatened Ecological Communities and other vegetation units referred to in government legislation. Assemblages were derived by a numerical analysis of 10832 field sample quadrats including 8523 compiled from 63 previous vegetation surveys. Past bias in the distribution of field data towards land under public tenure was corrected by extensive surveys carried out on private land. The classification revises and integrates the units described in recent vegetation studies of Eden, Cumberland Plain and Sydney-south coast into a single, consistent classification.

Relationships between floristic assemblages and climate, terrain, substrate and vegetation structure were used to map the distribution of communities prior to clearing at 1:100 000 scale. The extent of clearing was mapped using interpretations of remote imagery (1991–2001) from previous work, standardised and merged into a single coverage and supplemented with additional work. Profiles for each assemblage, which we term 'communities' or 'map units', describe their species composition, vegetation structure, environmental habitat, the extent of clearing and conservation status. Lists of diagnostic species were defined using a statistical fidelity measure and a procedure for using these for community identification is described.

Approximately 66% of the study area retains a cover of native vegetation, primarily in areas with low fertility soils and dissected topography. Communities subject to over-clearing (>70%) are concentrated in a few large areas characterised by clay/loam soils and flat to undulating terrain. These include the Sydney metropolis, Wingecarribee Plateau, Illawarra Plain, Shoalhaven floodplain, Araluen Valley and Bega Valley, and various smaller river valleys. Forty-one percent of remaining native vegetation is protected within conservation reserves while 31% occurs on private land, 20% in State Forests and 8% on other Crown lands. Forty-five Threatened Ecological Communities (TECs) were recorded in the study area. The majority of TECs are represented by a single map unit, although in some cases a TEC is included within a broader map unit. Twelve TECs are represented by combinations of two or more map units.

The full text, additional appendices and maps are provided on an accompanying CD.

***Cunninghamia* (2010) 11(3): 359–406**

Introduction

Native vegetation classifications and maps are widely used as a surrogate for biological diversity in landscape-level planning applications in NSW. Recent applications include the development of Regional Planning Strategies by the NSW Department of Planning; revision of Local Environmental Plans by local governments under the *Environmental Planning & Assessment Act 1979*; establishment, planning and management of conservation reserves under the *National Parks and Wildlife Act 1974*; management of water catchments under the *Sydney Water Catchment Management Act 1998*; assessment, listing and recovery of threatened ecological communities under the *Threatened Species Conservation Act* 1995; forestry reforms under the *National Forest Policy Statement 1992*; the setting of catchment-level targets and performance evaluation for vegetation management under the *Catchment Management Authorities Act 2003*; and monitoring, evaluation and reporting against native vegetation targets under the *NSW State Plan*. In addition to these fundamental strategic roles in landscape-scale planning, vegetation classifications and maps can provide useful contextual guidance for site-scale assessment of native vegetation, in tandem with appropriate field inspection.

© 2010 Botanic Gardens Trust

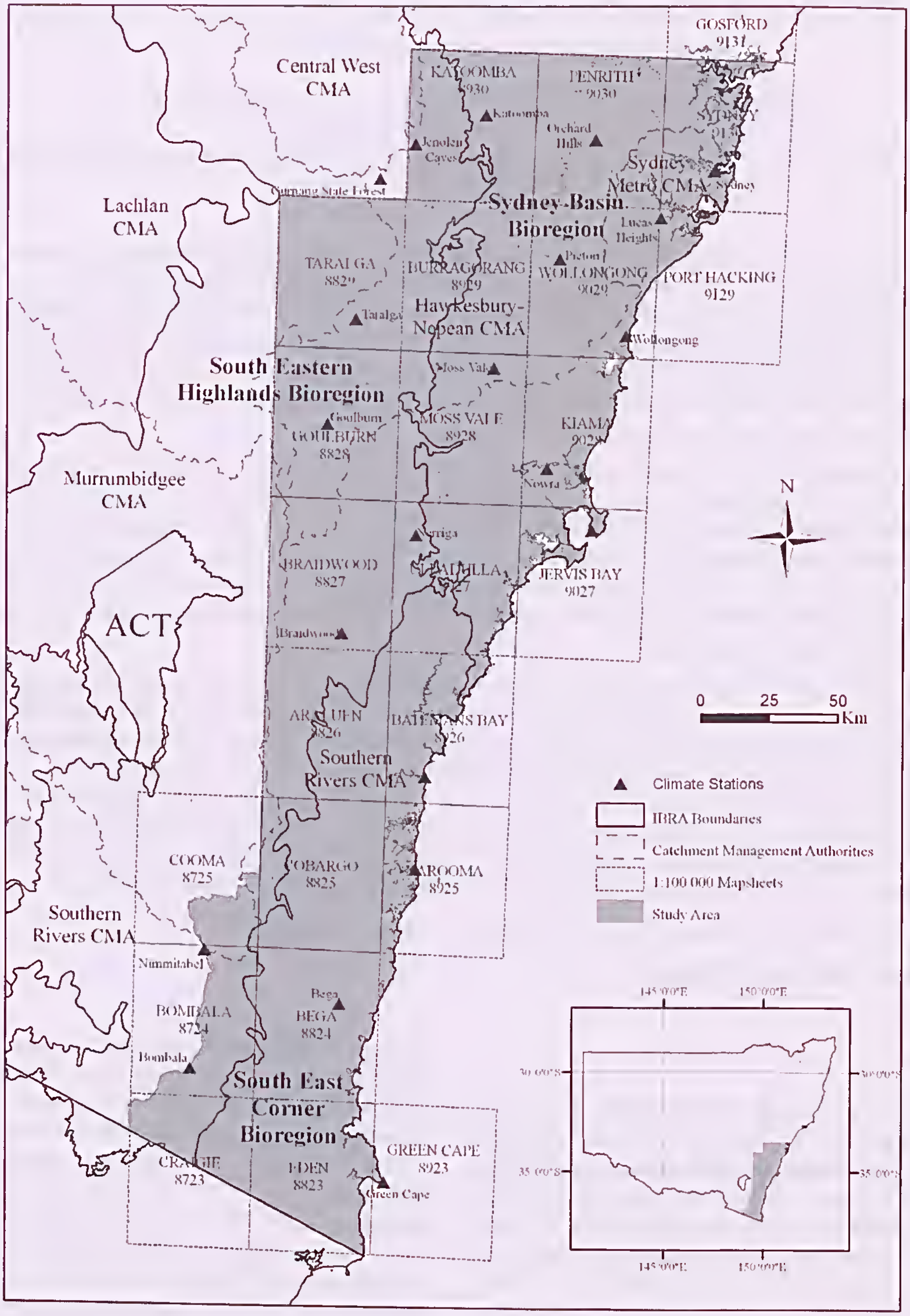


Fig. 1. Map of the study area showing the boundaries of bioregions, Catchment Management Areas, 1:100 000 map sheets and the location of weather stations referred to in Table 1.

If vegetation classifications and maps are to perform their roles effectively, they must closely represent landscape patterns in a regional biota (i.e. they must be realistic surrogates for biodiversity) and be robust to improvements in knowledge. The classifications and maps of vegetation that produce the most robust and informative generalisations about species distributions are those founded on quantitative sampling and analysis of biota (e.g. Rodwell *et al.* 2002) and systematic integration of compositional data with spatial data (e.g. Keith & Bedward 1999). The more comprehensive and more evenly stratified the sampling, the more robust and more representative of ecological patterns the resulting classifications and maps will be (Nicholson *et al.* 2009).

Systematic classification and mapping approaches were first applied to relatively small areas (Myerscough and Carolin 1986; Keith 1994). Surveys of conservation reserves in NSW now routinely involve quantitative sampling and numerical classification of vegetation, although a variety of approaches to the integration of floristic compositional data with spatial data have been used in map production (e.g. Clarke *et al.* 2000; Westbrooke *et al.* 1998; Keith *et al.* 2007) Hunter & Sherringham 2008. Systematic classification and mapping approaches were extended to regional scales in the NSW wheat belt (Sivertsen and Metcalfe 1995) and to forested regions of the coast and tablelands (Keith & Sanders 1990; Keith & Bedward 1999; Gellie 2005) as part of the Regional Forest Agreement process (Commonwealth of Australia 1992). The principles of systematic classification and mapping were subsequently adopted in a state-wide Native Vegetation Mapping Program (NVMP) for NSW (Sivertsen & Smith 2001) and continue to be applied in an expanding range of landscapes within the state (Benson & Ashby 2000; Ismay *et al.* 2004; McNellie *et al.* 2005; Tozer 2003; Peake 2005; Wall 2006).

The work presented here is the third revision of a vegetation classification and map originally produced for the NVMP and previously only available in unpublished form (Tindall *et al.* 2004; Tozer *et al.* 2006). Revision has included integration with the Eden region vegetation classification and map of Keith & Bedward (1999), and inclusion of additional recent field survey and spatial data.

In this paper, we demonstrate the feasibility of applying a systematic approach to classification and mapping of native vegetation across a large, physiographically complex and botanically diverse region extending over 4 million hectares from northern Sydney and the Blue Mountains to the NSW-Victorian border. Our aim was to produce a consistent regional typology and map of native vegetation to support various regional planning functions, which have included the development of biodiversity targets under the *Catchment Management Authorities Act 2003* and the development of Regional Planning Strategies for the Illawarra and South Coast regions. To support these planning functions, mapping of vegetation was required to produce accurate and robust estimates of the current extent and historical reduction in community distributions, although not necessarily a high level of fine-scale accuracy to support highly localised interpretation throughout the 4 million hectares.

To produce a vegetation classification and map, we synthesised a substantial base of floristic sample data and remote image interpretation from previous studies, and carried out additional field sampling and aerial photograph interpretation to fill gaps, enhance spatial resolution and update recent changes in land cover. We analysed the combined floristic data using a suite of numerical methods to produce a unified native vegetation classification for the study area. We then used the classified field samples to quantify the occurrence of each community in relation to combinations of aerial photo-pattern, substrate, topography and climate, and applied these relationships to spatial data layers to map the distribution of communities across southeast NSW. Remote image interpretations of clearing patterns were then used to trim these distributions to their current extent. Finally, we present novel descriptions and assessments of the classification and map to assist users in the diagnosis of plant communities and to understand the suitability of the classification and map for various applications.

Study Area

The study area is located between latitudes 33°30'S and 37°30'S and longitudes 149°00'E and 151°30'E in southeast New South Wales and is bounded by the coast from northern Sydney to the Victorian border and the escarpment and tablelands from the Blue Mountains to Delegate (Fig. 1). It comprises 4 006 650 hectares on twenty-three 1: 100 000 scale map sheets.

The study area covers all of the South Coast Botanical Subdivision as well as parts of the Central Coast (CC), Central Tablelands (CT) and Southern Tablelands (ST) (Harden 1990). The entire South East Corner bioregion in NSW is included, as well as parts of the Sydney Basin and South Eastern Highlands bioregions (Thackway & Cresswell 1995). The study area overlaps seven Catchment Management Authorities (CMAs), including the entire Sydney Metropolitan CMA and significant portions of the Hawkesbury/Nepean, Southern Rivers, and Lachlan CMAs. Minor areas of the Murrumbidgee, Central West and Hunter/Central Rivers CMAs overlap the periphery of the study area.

Topography

The coast of the study area features a narrow and interrupted coastal plain, which is most extensive east of Nowra on the Shoalhaven floodplain. Elsewhere it is confined to narrow strips of low-lying land, such as the Illawarra Plain, and is typically associated with coastal embayments, freshwater lagoons and lakes subject to intermittent tidal flushing. Narrow strips of floodplain extend inland along the lower reaches of larger rivers such as the Clyde, Moruya and Bega rivers.

In the north, the Sydney Basin is the dominant topographic feature, stretching from beyond the northern boundary of the study area, south to the Clyde River with an outer rim largely defined by the extent of the Morton, Woronora, Hornsby and Blue Mountains plateaux. These heavily dissected, elevated plateaux contrast with the Cumberland Plain, an expansive, low-lying coastal plain centrally located within the basin to the west of Sydney. The Blue Mountains Plateau rises steadily west of the Cumberland Plain as far as the Cox and Wollondilly River valleys. On the southeast margin of the basin, the Woronora Plateau rises in a ramp from the Nepean River to form an escarpment running roughly parallel to the coast from Port Hacking to the Budderoo Plateau. South of the Shoalhaven River the coastal hinterland is dominated by the Morton Plateau which extends south to the Clyde River valley. Like the Blue Mountains Plateau, the Morton Plateau is dissected by numerous streams and forms a west-east incline from the upper Shoalhaven River to the coast.

South of the Sydney Basin a coastal range rises to 300 – 600 m above sea level, punctuated by individual peaks up to 900 m (e.g. Mount Dromedary). Further west, an undulating hinterland featuring several rain shadow valleys, including those of the Araluen, Bega and Towamba Rivers, ends abruptly at the foot slopes of a rugged escarpment rising to form a mountain range (700–1000m) that marks the eastern edge of the southern tablelands. These tablelands are a very extensive undulating landscape, punctuated by low hills and exceeding 1300 m elevation on parts of the Great Dividing Range. The southern tablelands extend from west of the Blue Mountains southwards to the Monaro tableland.

Geology

The study area is dominated by the Sydney geological basin in the north and the older Lachlan fold belt in the south and along the western fringe (Branagan & Packham 2000). The Sydney basin comprises horizontal sediments of Triassic and Permian age. The youngest rocks, the Wianamatta shales, are found in the centre of the basin on the Cumberland Plain, with successively older rocks outcropping in a concentric pattern. The Wianamatta group comprises mainly siltstones, mudstones and claystones that yield moderately fertile clay loams. These contrast with very infertile sandy loams derived from the Hawkesbury sandstones found on the elevated plateaux that surround the plain. Further toward the margins of the basin, the Hawkesbury formation is succeeded by underlying rocks of the Triassic Narrabeen group and Permian Shoalhaven group. Both of these groupings comprise massive sandstone strata interbedded with narrower bands of claystone, siltstone and mudstone. These latter rocks weather more rapidly than the sandstones, and undercutting results in

Table 1: Summary of climate statistics for 21 selected weather stations within the study area (Bureau of Meteorology 2004).

Location	Region	Altitude (m)	Mean daily max temp (°C) (Jan)	Mean daily min temp (°C) (July)	Mean annual no days min ≤ 0.0 °C	Lowest mean monthly rainfall (mm)	Highest mean monthly rainfall (mm)	Mean annual rainfall (mm)
1. Sydney (Observatory Hill)	Sydney coastal	39	25.8	8	0	69.2 (Sep)	131.5 (Mar)	1219.8
2. Orchard Hills Treatment Works	Cumberland Plain	93	28.3	5.3	1.1	38.7 (Sep)	110.2 (Feb)	821.6
3. Lucas Heights (ANSTO)	Woronora plateau	140	25.9	6.6	0.1	51.9 (Sep)	117.9 (Mar)	1036.4
4. Katoomba (Narrowneck Rd)	Upper Blue Mountains	1030	23.1	2.5	13.1	72.9 (Sep)	173.7 (Feb)	1402.3
5. Oberon (Jenolan Caves)	Central gorges	730	25.6	0.2	50.4	66.7 (May)	93.8 (Jan)	966.2
6. Gurnang State Forest	Central tableland	1148	22.8	-1.6	98.4	72.7 (Apr)	94.4 (Jun)	991.7
7. Taralga (Post Office)	Central tableland	845	25.7	0.6	50.2	60.8 (Apr)	74.6 (Jun)	806.1
8. Picton (Council Depot)	Cumberland plain	165	29.3	3.2	32.4	44.0 (Sep)	88.8 (Mar)	806.2
9. Wollongong (University)	South coast lowlands	25	25.6	8.4	0	60.5 (Jul)	173.0 (Mar)	1354
10. Moss Vale (Hoskins St)	Southern highlands	675	25.8	1.3	31.1	60.7 (Sep)	99.8 (Jun)	976
11. Goulburn (Progress St)	Southern tableland	702	28.1	1.3	32.8	47.8 (Jul)	64.8 (Jan)	665.7
12. Braidwood (Wallace St)	Southern tableland	643	26	-0.2	59	47.5 (Jul)	71 (Jan)	722.8
13. Nerriga Composite	Southern tableland	630	26.1	0.2	58.5	54.6 (Sep)	76.1 (Mar)	767.8
14. Nowra (RAN Air Station)	South coast lowlands	109	25.8	6.2	0.1	55.7 (Jul)	130.4 (Mar)	1134.7
15. Jervis Bay (Point Perpendicular Lighthouse)	South coast lowlands	85	23.8	9.2	0.2	79.5 (Sep)	134.2 (May)	1245.4
16. Moruya Heads (Pilot Station)	South coast lowlands	17	23.9	5.9	0.1	54.3 (Aug)	109.3 (Mar)	963.2
17. Narooma Royal Volunteer Coastal Patrol	South coast lowlands	25	23.3	6.4	0	49.3 (Jul)	106.7 (Mar)	912.3
18. Nimmitabel (Post Office)	Southern Tablelands	1075	22.8	-1.9	104.1	46.9 (Aug)	68.7 (Jan)	690.6
19. Bombala (Therry St)	Southern Tablelands	705	25.2	-1.2	73.6	40.7 (Aug)	64.9 (Jan)	645.3
20. Bega (Newtown Rd)	Far South Coast	50	27.0	1.4	33.9	51.0 (Aug)	96.5 (Mar)	864.1
21. Green Cape Lighthouse	Far South Coast	20	21.6	8.4	0	45.6 (Aug)	78.2 (Jan)	749.7

the formation of sandstone cliffs that are characteristic of the western Blue Mountains, Illawarra escarpment and Morton plateau.

The Sydney basin unconformably overlies the Lachlan fold belt, which comprises contorted and variously metamorphosed rocks of Devonian, Silurian and Ordovician age (Branagan & Packham 2000). Primarily, these are metamorphosed mudstones, sandstones, conglomerates, slates, cherts, phyllites and quartzites. These rocks yield loamy soils of moderate fertility and outcrop over much of the area from south of the Victorian Border and northwards along the tableland beyond Taralga. The tableland also includes significant areas of acid volcanic rocks such as porphyry, tuff, rhyolite, andesite and felsite, particularly along the gorges of the Wollondilly and Shoalhaven rivers where the soils are relatively infertile loams. Localised outcrops of rhyolite are also found near Deua River, Tathra and to the north-west and south of Eden. Restricted outcrops of limestone occur at Jenolan, Abercrombie, Wombeyan, Bungonia, Wyanbene and Bendethera caves. These rocks weather to clay loams, rich in calcium. The Lachlan fold belt also includes large granite intrusions west of the Blue Mountains and Marulan and Braidwood (Bathurst batholith), and from Moruya south to the Victorian border (Bega batholith). These igneous intrusions include a great variety of granites, leucogranites, adamellites and granodiorites that produce sandy loams of varied nutrient status.

Basic volcanic rocks are relatively restricted, although significant basalt flows are found on the Kiama lowlands, the Robertson plateau, Taralga, Crookwell and the Monaro Tableland. Residual basalt caps occur on various peaks along the escarpment, including Mt Wilson and Mt Tomah in the Blue Mountains and Sassafras on the Morton plateau. The Blue Mountains also contain some highly localised diatremes, which mark the site of volcanic vents now filled with breccia. Further south, localised outcrops of basalt occur at Mt Darragh, Bull Mountain, Brown Mountain and Nethercote. The soils derived from basalts and dolerites are clays rich in a variety of mineral nutrients.

Unconsolidated sediments of Tertiary and Quaternary age occur along the coast and in localised sites on the tableland. The Tertiary deposits are associated with old streams and their floodplains. They comprise low-nutrient gravels, sands and clays and are mainly restricted to small areas on the Cumberland Plain and in the upper Shoalhaven River catchment. The coastline includes several sand plains of marine origin and a few small areas of perched aeolian dunes. Examples include the sand plains around Botany Bay and Port Hacking, Seven Mile Beach, Jervis Bay, Disaster Bay and the mouths of Burrill and Tabourie Lakes. These are sandy soils, whose fertility declines rapidly with age and distance from the salt-laden sea winds. Rich fluvial sediments are associated with the active floodplains of the coastal rivers. The largest areas are associated with the Hawkesbury River between Windsor and Camden, the Shoalhaven River downstream of Nowra, and the Bega and Moruya floodplains, although there are many other occurrences on the floodplains of smaller streams. These floodplains support deep nutrient-rich silts. Small areas of Quaternary alluvium also occur in the headwaters of streams where slopes are sufficiently flat to permit accumulation of sediment. These areas are typically boggy and may develop acid peats, as seen at Wingecarribee Swamp, Hanging Rock Swamp and numerous examples in the Blue Mountains and on the Woronora Plateau. However, the largest areas of alluvium on the tableland are Lake Bathurst, The Morass and the Mulwarree-Breadalbane plains, which have accumulated sediments from their respective closed drainage basins.

Climate

Most of the study area experiences a temperate climate featuring warm summers and cool winters on the coast and mild/warm summers and cold winters on the ranges and tablelands. The coastal lowlands around Sydney are at the southern limit of the north coast subtropical climate zone (Stern, de Hoedt & Ernst, 1999) and experience warmer, more humid summers than coastal areas further south. At the other extreme, areas of high elevation on the Gourock Range and Boyd Plateau fall within a montane cool temperate zone characterised by mild summers and occasional snow in winter. Daily and annual temperature variations are least in coastal areas, which also experience few frost days. Large areas of the tablelands experience on average 30–50 frost days per annum, while the Boyd Plateau experiences approximately 100 frost days per annum. Climate statistics from selected weather stations across the study area (Fig. 1) are presented in Table 1 (Commonwealth Bureau of Meteorology 2004).

Table 2: Cover/abundance scores for 6 and 7 class modified Braun-Blanquet scales.

Cover/abundance score	6 class scale	7 class scale
1	Uncommon and cover < 5%	Rare, one or few individuals present and cover < 5%
2	Common and cover < 5%	Uncommon and cover < 5%
3	5% ≤ cover < 20%	Common and cover < 5%
4	20% ≤ cover <50%	Very abundant and cover < 5%; or 5% ≤ cover < 20%
5	50% ≤ cover <75%	20% ≤ cover <50%
6	75% ≤ cover <100%	50% ≤ cover <75%
7	-	75% ≤ cover <100%

Precipitation varies across the study area in relation to altitude and distance from the coast, with higher rainfall areas found closer to the coast or at higher elevations. On the coastal lowlands, rainfall is generally higher in the north (>1000 mm per annum) than south of Batemans Bay (750 – 900 mm per annum). Orographic effects are particularly marked on the coastal escarpment between Nowra and the Royal National Park, the upper Blue Mountains, the southern escarpment from the Budawang Range to the Victorian border, including the Gourock Range, and isolated peaks on the coastal range. These areas receive on average at least 1100 mm of rainfall per year, with highest mean annual tallies exceeding 2000 mm at Barren Grounds. A number of rain shadow areas, where mean annual precipitation declines below 900mm (Table 1), occur among coastal plateaux and foothills, including the Cumberland Plain and the Araluen, Bega and Towamba valleys. The Monaro tableland in the far south-west of the study area is the driest rain shadow area, where mean annual precipitation falls below 600mm around Numeralla and Bombala. Throughout much of the area, rainfall is typically weakly seasonal with late summer months having higher rainfall, on average, than months from late winter to early spring.

Methods

Evaluation of Floristic Survey Data

Existing vegetation survey data were compiled from literature and databases held by land management agencies (e.g. Councils, Sydney Catchment Authority, State Forests of NSW, Department of Environment and Conservation; see Appendix 4). The following criteria were used to identify suitable quadrat data for analysis: i) the plot location was accurately recorded (±100m); ii) all vascular plant species were recorded with Braun-Blanquet cover/abundance estimates on either a 6 or 7 class scale (Table 2, Poore 1955, Sivertsen & Smith 2001); and iii) the quadrat area was 0.04 ha. A small number of eligible quadrats with larger dimensions (i.e. 0.1 ha) or without cover/abundance estimates were included in the data set where they sampled areas from which no other data were available.

Sample Stratification and Site Selection

New field sampling was carried out to increase the representation of environmental diversity of the study area. South from Batemans Bay, new sampling was primarily targeted at conservation reserves to verify existing regional vegetation maps (Keith & Bedward 1999, Gellie 2005), whereas further north new sampling covered all tenures and targeted sampling gaps on private land. Environmental diversity was represented in a Geographic Information System (GIS) by seven spatial variables on a 25m grid: terrain class (500m), aspect, slope, minimum temperature of the coldest period, maximum temperature of the warmest period, annual precipitation, and lithology (see Table 4 for explanation of variables). Environments that were under-represented by existing samples were identified by computing p-median scores (Faith & Walker 1996) which calculate the environmental dissimilarity of a point in the landscape compared with the most similar location represented by existing samples. P-median scores were interpolated for the entire study area based on 10 000 randomly selected locations (Ferrier 2002). Areas with the highest p-median values were given priority in the selection of new sample locations. The procedure was repeated iteratively throughout the survey period as new samples were acquired and the field survey plan was adjusted accordingly.

Field Sampling

Fieldwork was carried out from January 2001 until December 2006, with a total of 2309 new samples recorded. A Global Positioning System (GPS) device was used to navigate to chosen sample locations. Where necessary, the location was adjusted to ensure that the site characteristics matched the specified stratification parameters, that the terrain and soils were reasonably uniform across the plot and to avoid cleared areas. Additional sites were sampled if there appeared to be more than one type of vegetation community in the vicinity of the chosen location. Square survey quadrats of 0.04 ha were marked out using tape measures except where a rectangular configuration of the same area was required to ensure homogeneity of terrain and soils across the plot (e.g. along stream banks).

All vascular plant species rooted within or overhanging the quadrat were recorded and assigned a cover/abundance score. For historical reasons, the existing data sets south of Batemans Bay were based primarily on a 6-class Braun – Blanquet cover-abundance scale (Poore 1955, see Table 2), while those further north used a 7-class scale. To maximise compatibility with existing regional data sets, we continued to collect 6- and 7-class cover-abundance estimates in the north and south, respectively. The height range and projected foliage cover were estimated for all structural strata recognisable at the site (e.g. tree, small tree, shrub or forb), and a compass and clinometer were used to measure the aspect and slope at the centre of the quadrat, as well as horizon elevations at compass bearings of 0, 45, 90, 135, 180, 225, 270 and 315°. The location and elevation of the site were determined in the field using 1:25 000 topographic maps and/or a GPS. The soil type was determined by hand-texturing. Evidence of rock out-cropping, erosion, weed invasion, logging, soil disturbance or recent fire was noted.

Plant species that could not be identified in the field were collected for later identification. Where necessary, collections were sent for identification to the National Herbarium of NSW. Specimens that could not be identified to species level were not included in the analysis. Suitable voucher specimens were lodged at the Janet Cosh Herbarium (University of Wollongong) or the National Herbarium of

NSW. Nomenclature was standardised to follow Harden (1990 – 2002) and Flora Online [*plantnet.rbgsyd.nsw.gov.au/floraonline.htm]*. Exotic species were recorded but excluded from classification analysis.

Data Checking and Taxonomic Standardisation

Several data checking procedures were used to identify errors in the species recorded and spatial location of survey sites. Wherever possible, digital survey data were systematically checked against the original field data sheets to correct errors in data entry. The altitude of each survey site was estimated from its grid co-ordinates on a 25m digital elevation model for comparison with the corresponding value read from a map by the field observer. Where a discrepancy of more than 25m existed, or where no field value was recorded then the site location was cross-checked using the text descriptions on the data sheet and/or consultation with the observer. If the location could not be resolved to within 100m then the site was discarded. Grid references were compared among sites to identify and exclude any duplicate entries in the database.

Potential errors in species identification were checked by comparing distributions from the field data with published habitat descriptions and distributions (Harden 1990–2002; NSW DEC 2004a). A Geographic Information System was used to sort the survey sites into NSW botanical sub-regions and a separate species list was compiled for survey data from each observer in each botanical sub-region. Taxa recorded outside their published range were retained in the data provided the identification was reliable (e.g. voucher specimen lodged in a herbarium), the record was ecologically plausible (e.g. habitat matched the known distribution or the new record was not spatially isolated), or if the range extension was consistently recorded by multiple reliable observers. All taxa were checked for synonyms and for consistency in the naming of subspecies among observers. Any anomalies were corrected prior to analysis.

Cluster Analyses and Classification of Plant Communities

The data set compiled for analysis was derived from numerous sources, with different observers typically sampling non-overlapping spatial and physiographic domains. To assess potential observer-related artefacts, a sequence of analyses was carried out in PATN (Belbin 1994), starting with a reliable core of data and expanding to include subsets of additional data. Each iteration comprised a series of checks to identify misclassified sites, outliers and other anomalies. The classification was compiled in two stages. Firstly, a preliminary classification was derived from samples with 7-class cover-abundance estimates (primarily from north of Batemans Bay). Secondly, an expanded classification was derived after these data were standardised to 6-class cover-abundance estimates and combined with a large set of additional data in this latter format (primarily from south of Batemans Bay). Where both cover and abundance estimates were recorded the conversion was as follows (c/a = 1→1; c/a = 2→2; c/a = 3→2; c/a = 4 AND cover < 5% →2; c/a = 4 AND 5% ≤ cover < 20% →3; c/a = 5→4; c/a = 6→5; c/a = 7→6). For survey data in which cover and abundance were not differentiated all scores of c/a = 4 were converted to c/a = 3.For both analyses, dissimilarity among survey sites was computed from unstandardised data using a symmetric form of the Kulczynski coefficient (Faith 1991).

In the preliminary analysis, hierarchical agglomerative clustering was carried out using a flexible unweighted pair group arithmetic averaging strategy with no adjacency constraint and ß=-0.1. Provisional groups of sites were identified from the resulting dendrogram by interpreting lineages in the manner described by Keith & Bedward (1999). Homogeneity analysis (Bedward *et al.* 1992) was used to determine a preliminary level for interpreting lineages. Sister groups were recognised as distinct if there were obvious differences in species composition (Westhoff & van der Maarel 1978) and either spatial distribution or habitat characteristics of the constituent samples.

A non-hierarchical cluster analysis (Belbin 1987) was then carried out on the same data set to identify misclassified samples and search for clusters that may not have been identified in the hierarchical analysis. Centroids were calculated for the provisional groups described above and samples were allocated to centroids on the basis of Kulczynski dissimilarity values. The provisional classification of any given sample was reviewed if the most similar group centroid differed from its provisional allocation, or if the sample lay outside a dissimilarity threshold of 0.8 from any existing group centroid. New groups were added to the provisional classification if they were distinct from existing groups in species composition and either spatial distribution or habitat characteristics. The provisional classification was modified iteratively by including additional datasets from north of Batemans Bay that had been recorded by other observers (non-core data sources).

A supplementary analysis was carried out to assess potential differences among observers in the estimation of cover scores. This analysis compared the provisional classification with an alternative unseeded, non-hierarchical classification (maximum radius of 0.8 and 20 iterations) of the same samples, in which all cover/abundance estimates had been transformed to unity (presence/absence). Provisional groups which were composed primarily of samples from one non-core source, and which dissipated in the alternative classification, were subjected to further analysis of their floristic and physiographic characteristics in order to justify their retention in the classification.

The second stage of the classification followed a similar, iterative process to that described above, with subsets of data from south of Batemans Bay progressively added to the core dataset which, for this second set of analyses, had been transformed to 6-class cover-abundance estimates. This stage included two iterative, non-hierarchical analyses (i.e.

seeds were recalculated following the allocation of samples). In the first, the provisional groups were used as seeds and the stability of these groups was examined following three iterations. In the second, random seeds were used to derive a classification independent of previous classifications, to examine the robustness of the provisional groups. Where samples from different groups in the provisional classification were allocated to a single grouping in the unseeded classification, these units were merged. Conversely, if samples from the same provisional group were allocated to multiple groups in the unseeded classification, then consideration was given to expanding the classification by recognising additional groups.

All potentially outlying samples with centroid dissimilarity values > 0.7 (approximately one standard deviation above the mean) were examined for anomalies in the number of species present, spatial location and data provenance relative to other group members. Samples suspected to be incomplete due to very low species numbers (i.e. less than half the group median), or other anomalies such as doubtful species identifications, were discarded.

Community Descriptions and Field Identification

Final groups of classified sites were used to characterise the properties of the communities. Names given to communities were derived from a composite of location (e.g. south coast, Burragorang, Sydney), landform (e.g. rocky slopes, ridge, lowlands) and vegetation structure (e.g. forest, woodland, heath). If no obvious geographic location could be chosen then a substrate descriptor was used instead (e.g. basalt, coastal sands, sandstone). If the assemblage was distributed over a variety of landforms then a climatic descriptor was used instead (dry, wet, temperate). Where the properties of a final group of classified sites matched the description of a Threatened Ecological Community listed on Schedule 2 of the *NSW Threatened Species Conservation Act* (1995) then the community was given that name.

The alpha-numeric codes used to label map units reflected the origin of each unit. Units corresponding closely with a unit described in either Keith & Bedward (1999) or Tindall *et al.* (2004) retained their original number prefaced by "e" or "p" respectively. New units were prefaced with either an "n" or "m".

Descriptions of vegetation structure were compiled for each community from statistical summaries of estimates of structural variables recorded in the survey data. The height and projected foliage cover for each vertical stratum of vegetation were averaged (±s.d.) across all sample sites assigned to the community (these data were not available for all sites). The frequency with which each stratum was encountered in samples of the community was also calculated.

Lists of diagnostic species were derived for each community to assist with its identification in the field. Positive diagnostic species occurred more frequently within a map unit than in other map units (hypergeometric probability < 0.001). In order to minimize the inclusion of unreliable species, those occurring with frequency < 0.2 (within the community) and coefficient of variation > 0.05 were excluded (Tozer 2003). For each community, an estimate was made of the minimum number of positive diagnostic species expected in any 0.04 ha sample of that map unit (95% confidence interval). Using this estimate, map users may identify (with 95% confidence) an unknown vegetation community by enumerating the number of positive diagnostic species occurring in a randomly selected field sample.

Table 3: Vegetation Structural Categories used to standardise existing API data and carry out new API

Vegetation Structure Code	Vegetation Structural Category
SF1	Tall Wet Sclerophyll Forest
SF2	Low Dry Sclerophyll Forest
SF3	Tall Dry Sclerophyll Forest
SF4	Swamp Sclerophyll Forest
SF5	Tall Intermediate Sclerophyll Forest (Wet/Dry Transition)
MX1	Mixed Woodlands
RF1	Rainforest
RF2	Rainforest with emergent (5–10% CCP) Sclerophyll Forest
RF3	Fig Dry Rainforest
SS1	Littoral Rainforest (Sutherland Shire)
RV1	Riparian Forest
RV2	Riparian Scrub
RV3	Riparian Complex
HH1	Dry Heath (sandy substrates)
HH2	Dry Heath (rocky substrates)
HH3	*Allocasuarina nana* dominated Dry Heath
HH4	Wet Heath (moist substrates)
RO1	Rocky Outcrops
RO2	Rock Pavement Complexes
CS1	Coastal Scrub (rocky substrates)
CS2	Coastal Scrub (sandy substrates)
EB1	Banksia Scrub (Eastern Suburbs)
FP1	Floodplain Forests
MT1	Melaleuca Thickets
FW1	Floodplain Wetlands
SW1	Sand plain Wetlands
MW1	Montane Wetlands
US1	Upland Swamps (hanging swamps etc)
BF1	Bogs/Fens
GL1	Grassland
GL2	Moist Graminoid Complex
GL3	Strand Grasslands
CP1	Cypress Pine
AC1	Acacia Scrub
EV1	Mangroves
EV2	Salt marsh Complexes
EV3	Seagrass
EX3	Pioneering Dry Shrubs/Regrowth

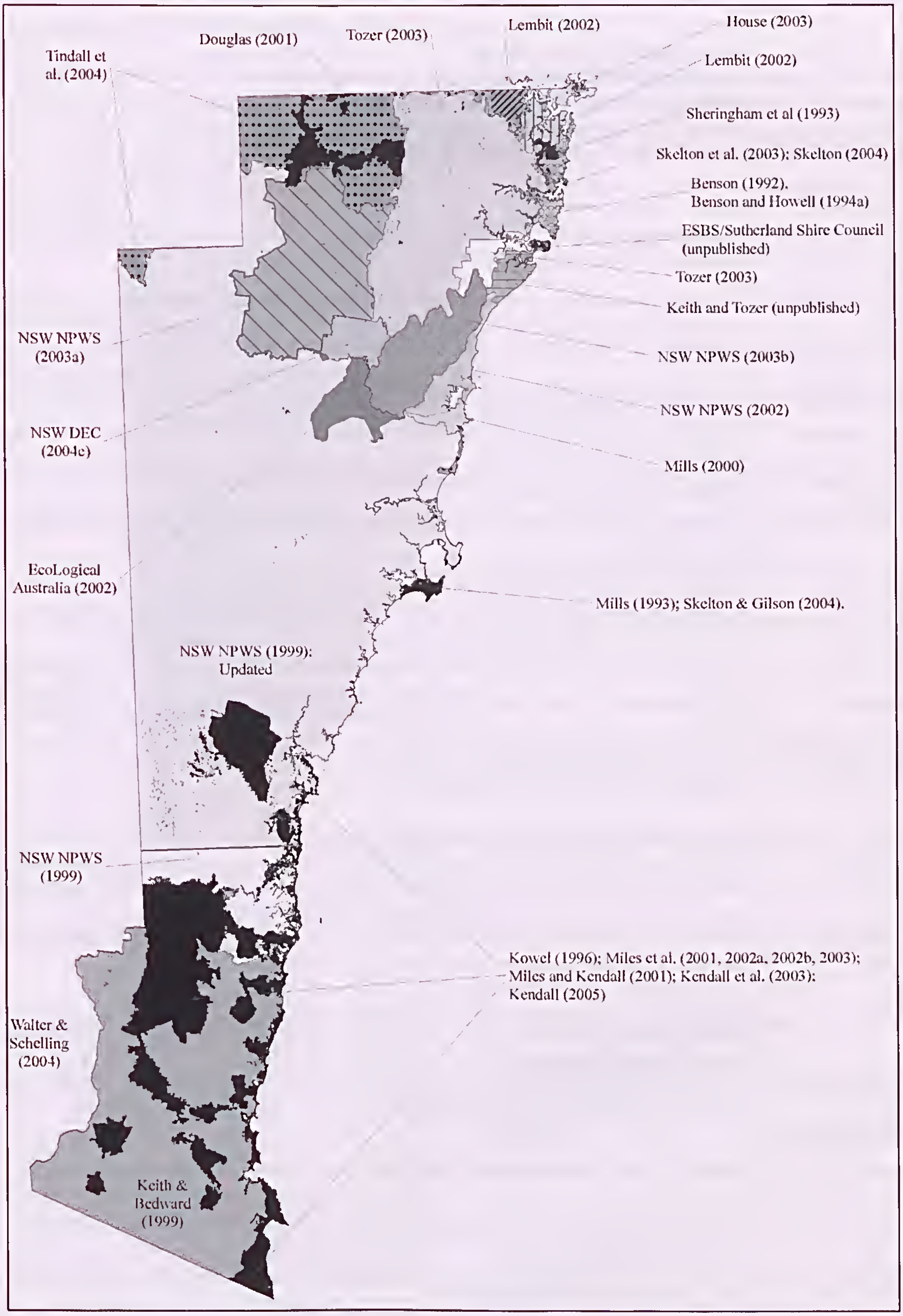

Tindall et al. (2004)
Douglas (2001)
Tozer (2003)
Lembit (2002)
House (2003)
Lembit (2002)
Sheringham et al (1993)
Skelton et al. (2003); Skelton (2004)
Benson (1992),
Benson and Howell (1994a)
ESBS/Sutherland Shire Council (unpublished)
Tozer (2003)
Keith and Tozer (unpublished)
NSW NPWS (2003a)
NSW NPWS (2003b)
NSW NPWS (2002)
NSW DEC (2004c)
Mills (2000)
EcoLogical Australia (2002)
Mills (1993); Skelton & Gilson (2004).
NSW NPWS (1999): Updated
NSW NPWS (1999)
Kowel (1996); Miles et al. (2001, 2002a, 2002b, 2003); Miles and Kendall (2001); Kendall et al. (2003); Kendall (2005)
Walter & Schelling (2004)
Keith & Bedward (1999)

Fig. 2. Sources of API vegetation spatial layers compiled into a seamless coverage for the study area.

Table 4: Spatial data layers used in modeling the distribution of vegetation communities

Spatial Variable	Description
Location	
Easting	Australian Map Grid Easting, Zone 56.
Northing	Australian Map Grid Northing, Zone 56.
Distance to coast	Shortest distance to nearest point of the coastline (metres).
Distance to stream	Shortest distance to stream of any size (metres).
Distance to stream (order ≤4)	Shortest distance to stream of size order 4 or greater (metres).
Terrain	
Elevation	Elevation above sea level (metres).
Wetness index	Continuous index representing the volume of water draining to a given location (after Moore et al. 1993).
Neighbourhood topographic roughness (250 m)	Standard deviation of elevation of cells within a neighbourhood of 250 by 250 metres.
Neighbourhood topographic roughness (500 m)	Standard deviation of elevation of cells within a neighbourhood of 500 by 500 metres.
Neighbourhood topographic roughness (1000 m)	Standard deviation of elevation of cells within a neighbourhood of 1000 by 1000 metres.
Neighbourhood topographic position (250 m)	Difference in elevation between an individual cell and the mean elevation of cells in the surrounding neighbourhood of 250 by 250 metres.
Neighbourhood topographic position (500 m)	Difference in elevation between an individual cell and the mean elevation of cells in the surrounding neighbourhood of 500 by 500 metres.
Neighbourhood topographic position (1000 m)	Difference in elevation between an individual cell and the mean elevation of cells in the surrounding neighbourhood of 1000 by 1000 metres.
Local topographic position	A measure of the position of each grid cell on a continuum between ridge (value = 100) and gully (value = 0) (after Skidmore 1990).
Slope	Inclination from horizontal (degrees).
Solar radiation (June)	Solar radiation received in June and corrected for terrain and rainfall (Megajoules.metres^{-2}.Day^{-1}).
Solar radiation (July)	Solar radiation received in July and corrected for terrain and rainfall (Megajoules.metres^{-2}.Day^{-1}).
Aspect (degrees)	Deviation from grid north of the horizontal component of the slope vector (in degrees).
Aspect index (southness)	Continuous index (0 – 100) calculated as 100 times sine of half of the aspect value (flat sites assigned missing values).
Aspect index (eastness)	Continuous index (0 – 100) calculated as 100 times sine of the aspect value in radians (flat sites assign missing values).
Ordinal Aspect Class (NNE)	Categorical index of aspect measured from NNE.
Ordinal Aspect Class (N)	Categorical index of aspect measured from N.
Substrate	
Soil landscapes	Integrated soil/topography classes from soil landscape maps.
Soil landscape lithology	Derived from soil landscape maps, dominant lithology classified as: high quartz sedimentary; low quartz sedimentary; transitional sedimentary; recent alluvium; inactive alluvium; coastal/marine sands; basaltic; granitic; acid volcanic; limestone; aeolian sediments; and excavated/filled land.
Geological formation	Geological formation responsible for surface soil features from geological/metallogenic maps (111 categories).
Geological group	Major groups of geological formations (12 categories Sydney Basin only).
Geological age	Age of geological formations (18 categories).
Geological lithology	Dominant lithology classified as: high quartz sedimentary; low quartz sedimentary; recent alluvium; inactive alluvium; coastal/ marine sands; basaltic; granitic; acid volcanic; limestone; and aeolian sediments derived from geological/metallogenic maps.
Coastal Quaternary Geology	Areas of coastal Quaternary sediment cover classified into broad classes: beach, dune, dune on rock, estuarine, dune wetland, saline wetland, riverine wetland, other alluvium, or covered by standing water.
Contemporary Vegetation Cover	
Vegetation structure	Vegetation structural categories derived from interpretation of recent remote imagery (see Table 3).
Climate	
Annual Mean Temperature	The mean of all the weekly mean temperatures. Each weekly mean temperature is the mean of that week's maximum and minimum temperature.
Mean Diurnal Range (Mean (period max-min))	The mean of all the weekly diurnal temperature ranges. Each weekly diurnal range is the difference between that week's maximum and minimum temperature.
Isothermality	The mean diurnal range divided by the Annual Temperature Range.
Temperature Seasonality (CV)	The temperature Coefficient of Variation (CV) is the standard deviation of the weekly mean temperatures expressed as a percentage of the mean of those temperatures (i.e. the annual mean). For this calculation, the mean in degrees Kelvin is used. This avoids the possibility of having to divide by zero, but does mean that the values are usually quite small.

Spatial Variable	Description
Max Temperature of Warmest Period	The highest temperature of any weekly maximum temperature.
Min Temperature of Coldest Period	The lowest temperature of any weekly minimum temperature.
Temperature Annual Range	The difference between the Max Temperature of Warmest Period and the Min Temperature of Coldest Period.
Mean Temperature of Wettest Quarter	The wettest quarter of the year is determined (to the nearest week), and the mean temperature of this period is calculated.
Mean Temperature of Driest Quarter	The driest quarter of the year is determined (to the nearest week), and the mean temperature of this period is calculated.
Mean Temperature of Warmest Quarter	The warmest quarter of the year is determined (to the nearest week), and the mean temperature of this period is calculated.
Mean Temperature of Coldest Quarter	The coldest quarter of the year is determined (to the nearest week), and the mean temperature of this period is calculated.
Annual Precipitation	The sum of all the monthly precipitation estimates.
Precipitation of Wettest Period	The precipitation of the wettest week or month, depending on the time step.
Precipitation of Driest Period	The precipitation of the driest week or month
Precipitation Seasonality (CV)	The Coefficient of Variation (CV) is the standard deviation of the weekly precipitation estimates expressed as a percentage of the mean of those estimates (i.e. the annual mean).
Precipitation of Wettest Quarter	The wettest quarter of the year is determined (to the nearest week), and the total precipitation over this period is calculated.
Precipitation of Driest Quarter	The driest quarter of the year is determined (to the nearest week), and the total precipitation over this period is calculated.
Precipitation of Warmest Quarter	The warmest quarter of the year is determined (to the nearest week), and the total precipitation over this period is calculated.
Precipitation of Coldest Quarter	The coldest quarter of the year is determined (to the nearest week), and the total precipitation over this period is calculated.
Annual Mean Radiation	The mean of all the weekly radiation estimates.
Highest Period Radiation	The highest radiation estimate for all weeks.
Lowest Period Radiation	The lowest radiation estimate for all weeks
Radiation Seasonality (CV)	The Coefficient of Variation (CV) is the standard deviation of the weekly radiation estimates expressed as a percentage of the mean of those estimates (i.e. the annual mean).
Radiation of Wettest Quarter	The wettest quarter of the year is determined (to the nearest week), and the average radiation over this period is calculated.
Radiation of Driest Quarter	The driest quarter of the year is determined (to the nearest week), and the average radiation over this period is calculated.
Radiation of Warmest Quarter	The warmest quarter of the year is determined (to the nearest week), and the average radiation over this period is calculated.
Radiation of Coldest Quarter	The coldest quarter of the year is determined (to the nearest week), and the average radiation over this period is calculated.

Threatened Ecological Communities and Threatened Flora

Several Threatened Ecological Communities (TECs) listed under either NSW (*Threatened Species Conservation Act* 1995) or Australian (*Environment Protection and Biodiversity Conservation Act* 1999) government legislation are known to occur within the study area. Some estuarine and marine plant communities may also be Protected Marine Vegetation under the NSW *Fisheries Management Act* 1994. Relationships between communities described in this study and those listed as threatened were investigated by comparing the descriptions of their corresponding properties (i.e. characteristic species, habitat and distribution).

Relationships with other classifications

Relationships between the communities described here and those described in previous classifications were explored by comparing the allocation of samples to units in the respective classifications. Comparisons were restricted to previous classifications that covered appreciable portions of the study area (Fig. 1), incorporated a substantial set of shared samples and were derived from similar numerical clustering methods to those described here. These included surveys of the Southeast forests region (Keith & Bedward 1999), Southern Comprehensive Regional Assessment (Gellie 2005), Illawarra (NSW NPWS 2002) and Warragamba Special Area (NSW NPWS 2003a). Comparisons were made by obtaining the allocations of samples to classification units made by each author and compiling cross-tabulation matrices of sample numbers assigned to each pair-wise combination of units from the respective classifications. Matrices were range-standardised by row and column totals in turn to highlight points of correspondence between classifications. Communities were also assigned to NSW Structural Formations and Vegetation Classes (Keith 2004) on the basis of floristic and structural features as well as distribution.

Remote sensing of contemporary vegetation cover

A map of contemporary vegetation cover was produced by compiling and upgrading remote image interpretation data from 25 previous studies (Fig. 2). The majority of these studies (Appendix 5) were based on traditional aerial photograph interpretation, in which polygons were drawn manually to delineate spatial vegetation features onto acetate overlaying contact prints that were examined with stereoscopic viewers. The linework was subsequently scanned into digital format, ortho-rectified using suitable geo-reference control points and attributed with the interpreted vegetation features. Exceptions included the Monaro tablelands (Walter & Schelling 2004), where native grasslands were mapped by multi-temporal spectral classification of Landsat TM imagery, and the Eden region (Keith & Bedward 1999), in which structural classes were initially delineated by interpreting aerial photos flown in 1963, with clearing boundaries updated using automated classification of Landsat TM captured in 1994, and then enhanced to finer resolution and further updated using colour aerial photography (Appendix 6).

The available remote sensing data sets were evaluated using four criteria based on those described by Keith & Simpson (2006):

i) thematic compatibility (units assignable to common structural categories, Table 3);

ii) accuracy (assessed by overlaying linework on imagery; Keith *et al.* 2000);

iii) precision or resolution (minimum remnant size 1 ha; crown cover 5%); and

iv) currency (imagery captured after 1991).

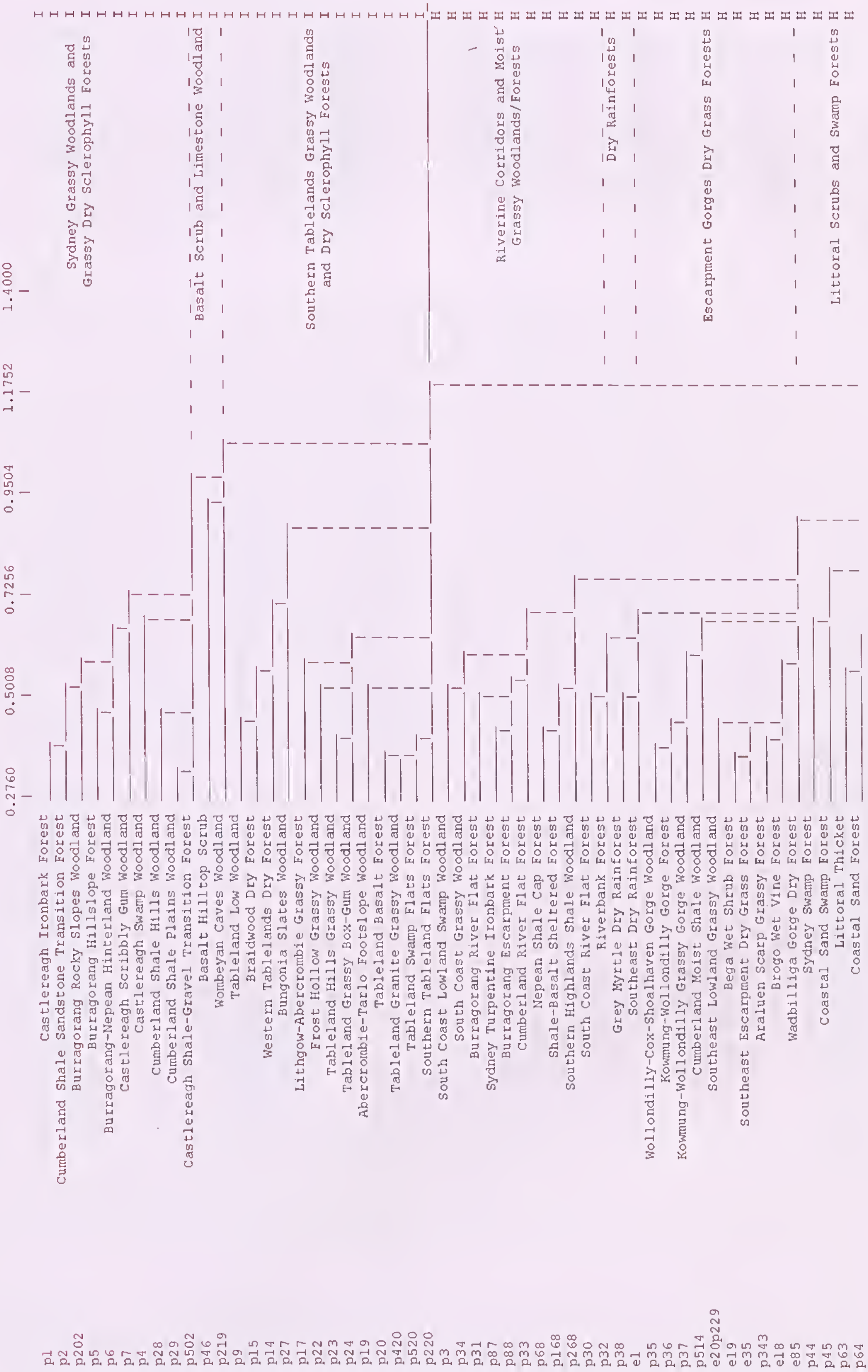
Boundary accuracy (criterion ii) was checked by comparing linework with vegetation boundaries using ortho-rectified aerial photography on a GIS (Keith *et al.* 2000). Linework that varied by more than 20m (average) from the boundary positions on the photographs was considered unreliable and discarded. Where the criterion iii (resolution) could not be met, the best available map was identified and enhanced as required (see below). Maps based on imagery older than 1991 were only considered in areas that were unlikely to have undergone subsequent land clearing (e.g. conservation reserves).

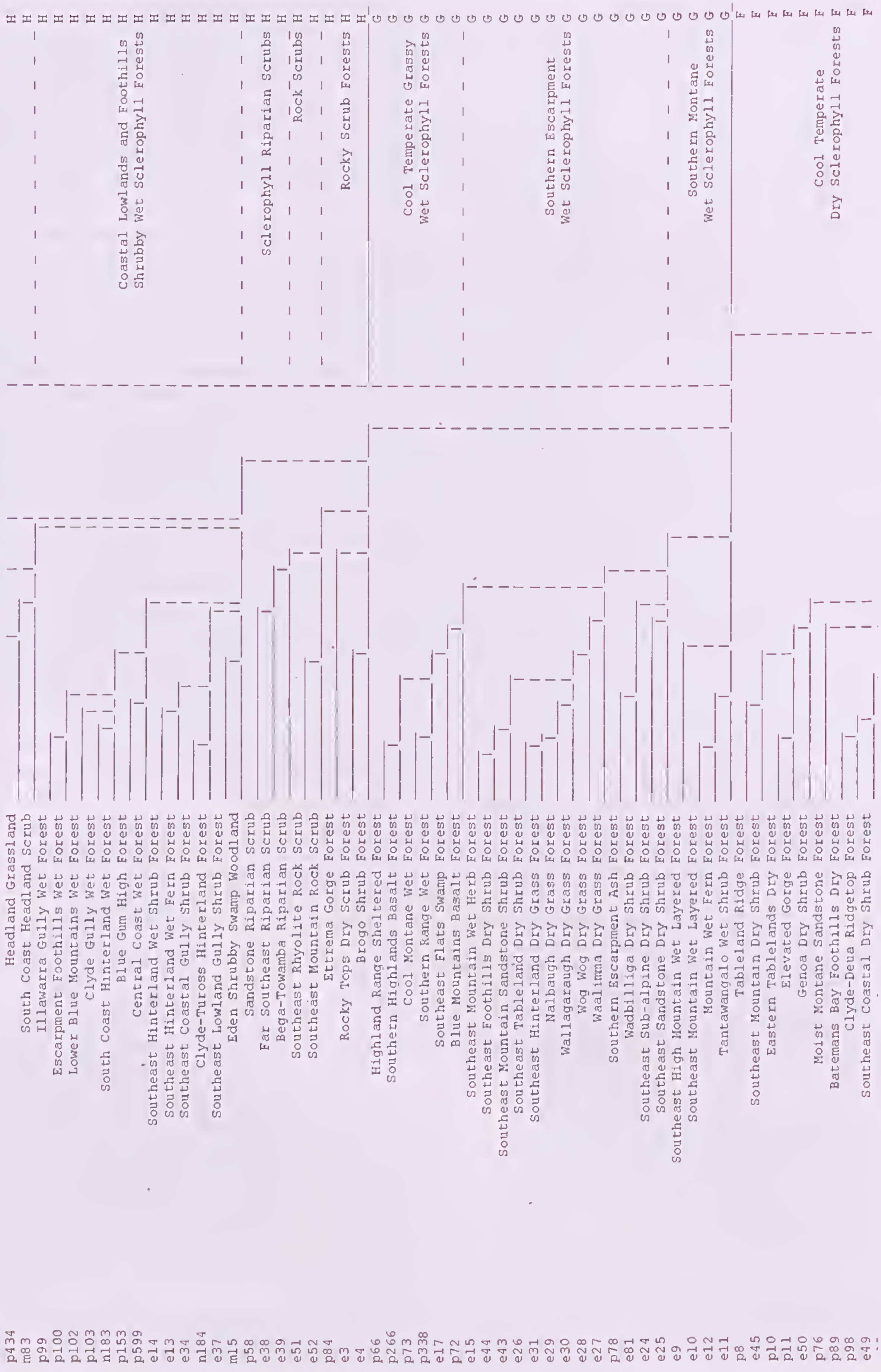
Prior to merging, maps were thematically standardised by assigning all maps units to common structural categories (Table 3). Where adjacent maps matched poorly along their boundaries after standardisation, alternative assignments of their units were examined to resolve conflicts. Maps with poor compatibility were discarded. A seamless coverage of contemporary vegetation cover was compiled from the suitable data sets using a GIS. Where layers overlapped, layers with greater geographic range, a more recent date of interpretation, greater spatial accuracy and greater attribute accuracy were used in preference to layers with lesser attributes. The merged coverage was checked for gaps and consistency where individual coverages were joined.

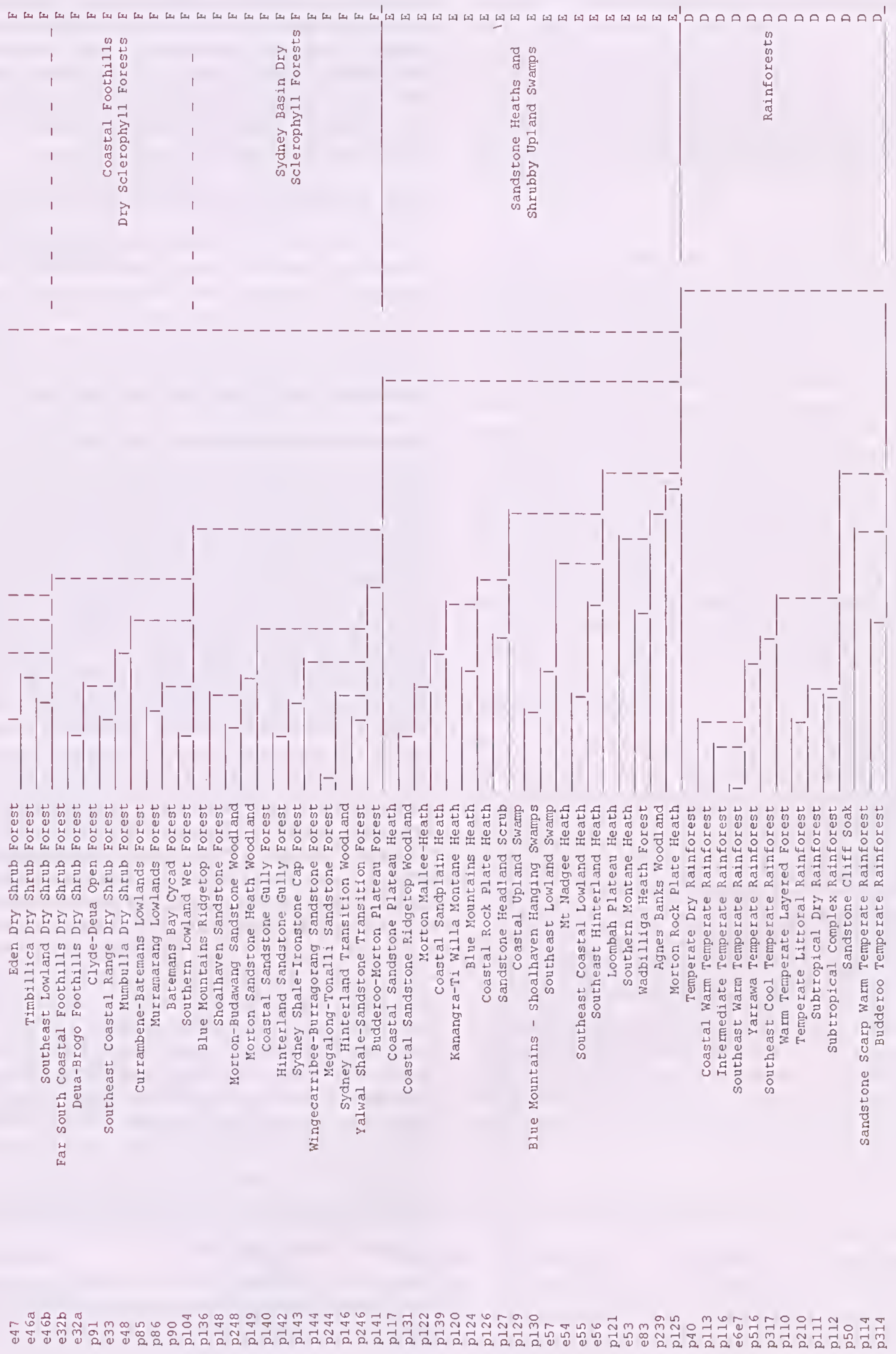
Supplementary aerial photograph interpretation using digital orthophotos and/or stereoscopic pairs was carried out to improve resolution and fill gaps in the map coverage identified during the checking process. Enhancements to existing linework were undertaken, where possible, using the original air photos and hand-marked acetate overlays. Modifications and additions to linework and attributes were done digitally in a GIS using either rectified digital ortho-photo mosaics or recent Landsat 7-TM satellite imagery (small areas of the Taralga and Goulburn map sheets) as a base. Details of imagery used to update existing API layers are provided in Appendix 6. As well as upgrades to resolution of linework, enhancements included delineation of bogs and fens throughout cleared land on the tableland and delineation of native grasslands on coastal headlands, as these features were poorly represented in the existing data sets. In most cases the digital base layers were more recent than the original aerial photography and some differences were detected in the boundaries of the extant vegetation. These boundaries were updated during digitisation. Gaps in the map coverage were filled by interpreting the structural categories directly from colour stereo pairs (Appendix 6). Boundaries were delineated on clear acetate air photo overlays and then digitised in a GIS using rectified digital ortho-photo mosaics as a base.

Environmental Data

A set of spatial data layers was created for modelling the distributions of vegetation map units (Table 4). The data layers were derived and manipulated in digital raster format at a grid cell resolution of 25 m in Zone 55 of the Australian Grid Datum 66 using a GIS. Location variables were derived directly from the grid datum and by calculating distance from vectors representing landscape features (Table 4). The terrain variables included a range of indices computed at grid neighbourhoods of varying size (Table 4). Climatic variables representing temperature, precipitation and solar radiation were derived from the digital elevation model and long-term meteorological data using ESOCLIM (Hutchinson 1989). Substrate data layers were compiled from soil landscape (1:100 000) and geological/metallogenic (1:250 000, 1:100 000 or 1:25 000) mapping (Bannerman & Hazelton 1990, Barnes *et al.* 2005, Chapman & Murphy 1989, NSW DLWC 1999 and 2002, NSW DNR 2006, Hazelton 1990 and 1992,


0.2760
0.5008
0.7256
0.9504
1.1752
1.4000
p1 Castlereagh Ironbark Forest
p2 Cumberland Shale Sandstone Transition Forest
p202 Burragorang Rocky Slopes Woodland
p5 Burragorang Hillslope Forest
p6 Burragorang-Nepean Hinterland Woodland
p7 Castlereagh Scribbly Gum Woodland
p4 Castlereagh Swamp Woodland
p28 Cumberland Shale Hills Woodland
p29 Cumberland Shale Plains Woodland
p502 Castlereagh Shale-Gravel Transition Forest
p46 Basalt Hilltop Scrub
p219 Wombeyan Caves Woodland
p9 Tableland Low Woodland
p15 Braidwood Dry Forest
p14 Western Tablelands Dry Forest
p27 Bungonia Slates Woodland
p17 Lithgow-Abercrombie Grassy Forest
p22 Frost Hollow Grassy Woodland
p23 Tableland Hills Grassy Woodland
p24 Tableland Grassy Box-Gum Woodland
p19 Abercrombie-Tarlo Footslope Woodland
p20 Tableland Basalt Forest
p420 Tableland Granite Grassy Woodland
p520 Tableland Swamp Flats Forest
p220 Southern Tableland Flats Forest
p3 South Coast Lowland Swamp Woodland
p34 South Coast Grassy Woodland
p31 Burragorang River Flat Forest
p87 Sydney Turpentine Ironbark Forest
p88 Burragorang Escarpment Forest
p33 Cumberland River Flat Forest
p68 Nepean Shale Cap Forest
p168 Shale-Basalt Sheltered Forest
p268 Southern Highlands Shale Woodland
p30 South Coast River Flat Forest
p32 Riverbank Forest
p38 Grey Myrtle Dry Rainforest
e1 Southeast Dry Rainforest
p35 Wollondilly-Cox-Shoalhaven Gorge Woodland
p36 Kowmung-Wollondilly Gorge Forest
p37 Kowmung-Wollondilly Grassy Gorge Woodland
p514 Cumberland Moist Shale Woodland
e20p229 Southeast Lowland Grassy Woodland
e19 Bega Wet Shrub Forest
e35 Southeast Escarpment Dry Grass Forest
p343 Araluen Scarp Grassy Forest
e18 Brogo Wet Vine Forest
e85 Wadbilliga Gorge Dry Forest
p44 Sydney Swamp Forest
p45 Coastal Sand Swamp Forest
p63 Littoral Thicket
p64 Coastal Sand Forest
Sydney Grassy Woodlands and Grassy Dry Sclerophyll Forests
Basalt Scrub and Limestone Woodland
Southern Tablelands Grassy Woodlands and Dry Sclerophyll Forests
Riverine Corridors and Moist Grassy Woodlands/Forests
Dry Rainforests
Escarpment Gorges Dry Grass Forests
Littoral Scrubs and Swamp Forests
]


p434 Headland Grassland H
m83 South Coast Headland Scrub H
p99 Illawarra Gully Wet Forest H
p100 Escarpment Foothills Wet Forest H
p102 Lower Blue Mountains Wet Forest H
p103 Clyde Gully Wet Forest H
n183 South Coast Hinterland Wet Forest H
p153 Blue Gum High Forest H
p599 Central Coast Wet Forest H
e14 Southeast Hinterland Wet Shrub Forest H
e13 Southeast Hinterland Wet Fern Forest H
e34 Southeast Coastal Gully Shrub Forest H
n184 Clyde-Tuross Hinterland Forest H
e37 Southeast Lowland Gully Shrub Forest H
m15 Eden Shrubby Swamp Woodland H
p58 Sandstone Riparian Scrub H
e38 Far Southeast Riparian Scrub H
e39 Bega-Towamba Riparian Scrub H
e51 Southeast Rhyolite Rock Scrub H
e52 Southeast Mountain Rock Scrub H
p84 Ettrema Gorge Forest H
e3 Rocky Tops Dry Scrub Forest H
e4 Brogo Shrub Forest H
p66 Highland Range Sheltered Forest G
p266 Southern Highlands Basalt Forest G
p73 Cool Montane Wet Forest G
p338 Southern Range Wet Forest G
e17 Southeast Flats Swamp Forest G
p72 Blue Mountains Basalt Forest G
e15 Southeast Mountain Wet Herb Forest G
e44 Southeast Foothills Dry Shrub Forest G
e43 Southeast Mountain Sandstone Shrub Forest G
e26 Southeast Tableland Dry Shrub Forest G
e31 Southeast Hinterland Dry Grass Forest G
e29 Nalbaugh Dry Grass Forest G
e30 Wallagaraugh Dry Grass Forest G
e28 Wog Wog Dry Grass Forest G
e27 Waalimma Dry Grass Forest G
p78 Southern Escarpment Ash Forest G
e81 Wadbilliga Dry Shrub Forest G
e24 Southeast Sub-alpine Dry Shrub Forest G
e25 Southeast Sandstone Dry Shrub Forest G
e9 Southeast High Mountain Wet Layered Forest G
e10 Southeast Mountain Wet Layered Forest G
e12 Mountain Wet Fern Forest G
e11 Tantawangalo Wet Shrub Forest G
p8 Tableland Ridge Forest F
e45 Southeast Mountain Dry Shrub Forest F
p10 Eastern Tablelands Dry Forest F
p11 Elevated Gorge Forest F
e50 Genoa Dry Shrub Forest F
p76 Moist Montane Sandstone Forest F
p89 Batemans Bay Foothills Dry Forest F
p98 Clyde-Deua Ridgetop Forest F
e49 Southeast Coastal Dry Shrub Forest F
Coastal Lowlands and Foothills Shrubby Wet Sclerophyll Forests
Sclerophyll Riparian Scrubs
Rock Scrubs
Rocky Scrub Forests
Cool Temperate Grassy Wet Sclerophyll Forests
Southern Escarpment Wet Sclerophyll Forests
Southern Montane Wet Sclerophyll Forests
Cool Temperate Dry Sclerophyll Forests


e47 Eden Dry Shrub Forest F
e46a Timbillica Dry Shrub Forest F
e46b Southeast Lowland Dry Shrub Forest F
e32b Far South Coastal Foothills Dry Shrub Forest F
e32a Deua-Brogo Foothills Dry Shrub Forest F
p91 Clyde-Deua Open Forest F
e33 Southeast Coastal Range Dry Shrub Forest F
e48 Mumbulla Dry Shrub Forest F
p85 Currambene-Batemans Lowlands Forest F
p86 Murramarang Lowlands Forest F
p90 Batemans Bay Cycad Forest F
p104 Southern Lowland Wet Forest F
p136 Blue Mountains Ridgetop Forest F
p148 Shoalhaven Sandstone Forest F
p248 Morton-Budawang Sandstone Woodland F
p149 Morton Sandstone Heath Woodland F
p140 Coastal Sandstone Gully Forest F
p142 Hinterland Sandstone Gully Forest F
p143 Sydney Shale-Ironstone Cap Forest F
p144 Wingecarribee-Burragorang Sandstone Forest F
p244 Megalong-Tonalli Sandstone Forest F
p146 Sydney Hinterland Transition Woodland F
p246 Yalwal Shale-Sandstone Transition Forest F
p141 Budderoo-Morton Plateau Forest F
p117 Coastal Sandstone Plateau Heath E
p131 Coastal Sandstone Ridgetop Woodland E
p122 Morton Mallee-Heath E
p139 Coastal Sandplain Heath E
p120 Kanangra-Ti Willa Montane Heath E
p124 Blue Mountains Heath E
p126 Coastal Rock Plate Heath E
p127 Sandstone Headland Scrub E
p129 Coastal Upland Swamp E
p130 Blue Mountains - Shoalhaven Hanging Swamps E
e57 Southeast Lowland Swamp E
e54 Mt Nadgee Heath E
e55 Southeast Coastal Lowland Heath E
e56 Southeast Hinterland Heath E
p121 Loombah Plateau Heath E
e53 Southern Montane Heath E
e83 Wadbilliga Heath Forest E
p239 Agnes Banks Woodland E
p125 Morton Rock Plate Heath E
p40 Temperate Dry Rainforest D
p113 Coastal Warm Temperate Rainforest D
p116 Intermediate Temperate Rainforest D
e6e7 Southeast Warm Temperate Rainforest D
p516 Yarrawa Temperate Rainforest D
p317 Southeast Cool Temperate Rainforest D
p110 Warm Temperate Layered Forest D
p210 Temperate Littoral Rainforest D
p111 Subtropical Dry Rainforest D
p112 Subtropical Complex Rainforest D
p50 Sandstone Cliff Soak D
p114 Sandstone Scarp Warm Temperate Rainforest D
p314 Budderoo Temperate Rainforest D
Coastal Foothills Dry Sclerophyll Forests
Sydney Basin Dry Sclerophyll Forests
Sandstone Heaths and Shrubby Upland Swamps
Rainforests

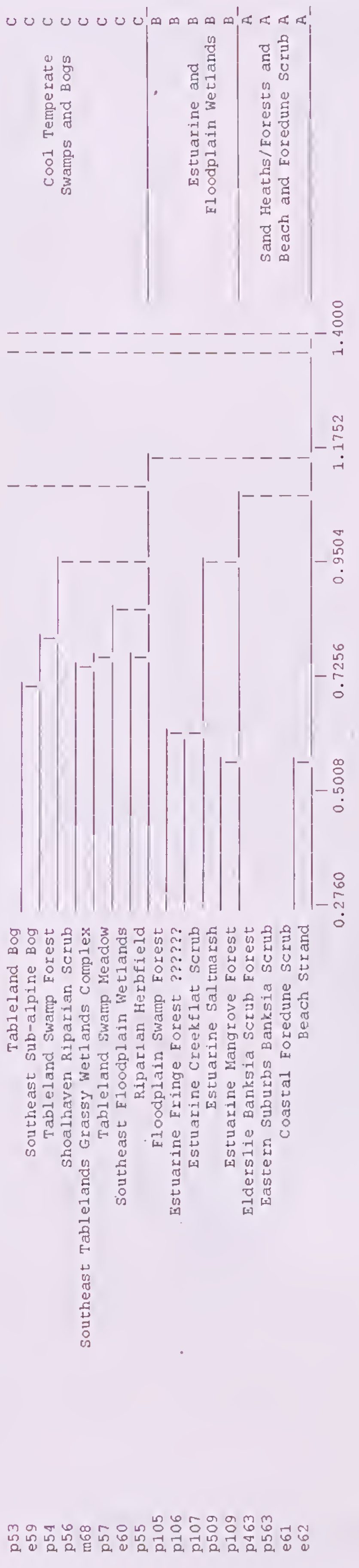

p53 Tableland Bog C
e59 Southeast Sub-alpine Bog C
p54 Tableland Swamp Forest C
p56 Shoalhaven Riparian Scrub C
m68 Southeast Tablelands Grassy Wetlands Complex C
p57 Tableland Swamp Meadow C
e60 Southeast Floodplain Wetlands C
p55 Riparian Herbfield C
p105 Floodplain Swamp Forest B
p106 Estuarine Fringe Forest ????? B
p107 Estuarine Creekflat Scrub B
p509 Estuarine Saltmarsh B
p109 Estuarine Mangrove Forest B
p463 Eldersile Banksia Scrub Forest A
p563 Eastern Suburbs Banksia Scrub A
e61 Coastal Foredune Scrub A
e62 Beach Strand A
Cool Temperate Swamps and Bogs
Estuarine and Floodplain Wetlands
Sand Heaths/Forests and Beach and Foredune Scrub
0.2760
0.5008
0.7256
0.9504
1.1752
1.4000

Fig. 3. Dendrogram showing hierarchical relationships between Map Units.

Jenkins 1996, King 1994, Bryan 1966, Rose 1966a and 1966b, Brunker & Offenberg 1970, Best *et al.* 1963, Stevens 1968, Felton 1974, McIlveen 1973, Gilligan 1974, Raymond & Pogson 1998, Pogson & Watkins 1998, Lewis & Glen 1995, Scheibner 1973, Clark & Jones 1991, Wyborn & Owen 1982, Felton & Huleatt 1975). Layers for contemporary native vegetation cover and structural categories were derived from remote sensing as outlined above.

Spatial Modelling of Communities and Map Compilation

A map showing the reconstructed distributions of the communities across the entire landscape was prepared using the geo-referenced field samples assigned to each community and the spatial data layers (Table 4) to interpolate the occurrence of communities across both cleared and vegetated parts of the landscape. This map of reconstructed (pre-clearing) vegetation patterns was then intersected with the map of contemporary native vegetation cover to obtain a map of the extant distributions of communities.

Interpolation was done by first constructing a matrix of field samples, the community to which they had been assigned (dependent variable), and the relevant values of each spatial parameter listed in Table 4 (independent variables) obtained by intersecting sample locations and these spatial data layers. The data matrix was then used to develop decision rules quantifying the occurrence of each community in relation to multi-dimensional envelope(s) defined by the spatial data variables. Finally, the distributions of communities were mapped in a GIS by intersecting and merging the relevant spatial data layers to implement the decision rules.

The decision rules were developed iteratively over several cycles of modelling, evaluation, deconstruction and revision using ALBERO, a hybrid decision tree/expert system with a mapping module that translates the decision rules into a vegetation map using the spatial data layers specified in the rules (Keith & Bedward 1999). This technique uses a divisive strategy in which a sequence of spatial variables is used to progressively split the full set of samples into smaller and smaller groups. Splitting is performed in a dichotomous manner that seeks to maximise discrimination between each pair of daughter groups with respect to the communities represented in their component samples. The splits were determined jointly by the authors, who were familiar with both the data set and the landscape. ALBERO informs the operators' selection of decision rules by providing a list of variables at each node which could be used to discriminate groups of samples assigned to different communities. It also calculates Chi-squared values as indicators of the discriminatory power of each variable in each node, and these were used to inform the successive expert selections of variables in each decision rule.

The modelled distribution of each community was assessed by comparing the mapped output with the distribution of the sample sites, as well as expert knowledge, field notes and published and unpublished reports for particular locations. Supplementary ground-truthing was also carried out for this purpose. The causes of discrepancies in the map were diagnosed by de-constructing the decision rules and exploring the efficacy of alternative sub-rules. The decision rules were revised where this could improve the agreement between the mapped output and the available information sources.

Many of the smallest patches of vegetation shown on the mapped output were identified as artefacts of the spatial intersection process. To remove these artefacts, features less than 0.5 ha in area were nibbled away and replaced by adjacent map units.

Results

Cluster Analysis and Classification of Plant Communities

Data collected from 10 832 survey sites met the criteria for inclusion in the cluster analyses. Of these, 2 297 sites could not be reliably assigned to classes due to conflicts between their dendrogram grouping and nearest neighbour checks, and were therefore omitted from further analysis. A total of 8 535 sites were assigned to 190 floristic assemblages (communities) which made up the final classification. The hierarchical classification grouped these assemblages into nine major lineages on the basis of shared floristic features (Fig. 3; parts A – I). These higher-order groupings also reflected strong structural and physiognomic relationships, as five were directly aligned with state-wide structural formations described by Keith (2004): Parts C (Freshwater Wetlands D (Rainforests); E (Heathlands); F (Dry Sclerophyll Forests –shrubby sub-formation); and G (Wet Sclerophyll Forests). Part I comprised communities of two formations: Grassy Woodlands and Dry Sclerophyll Forests (grassy sub-formation). Several lineages could be further divided into geographic or climatic sub-groups (e.g. Parts F, G &I). Part H comprised a set of sub-groups typically occurring in moist sites (either sheltered or with impeded drainage), often in rugged terrain.

Species Richness

A total of 2 894 taxa were recorded in the 8 535 survey sites classified. Of these, 2 347 were native, representing approximately 25% of the recorded native flora of NSW (NSW DEC, 2004a). Approximately 28 % of native species were recorded five times or less (i.e. present in <0.1% of sites) and 12 % were recorded only once. Only four native species were recorded in greater than 30% of sites; these were *Lomandra longifolia* (44%), *Entolasia stricta* (34%), *Microlaena stipoides* (36%) and *Pteridium esculentum* (37%). Native species richness varied considerably between floristic groups, with the mean (±s.d.) species richness per sample plot ranging from 3.9 (±2.9) for Estuarine Saltmarsh (SL p509) to 51.9 (±12.1) for Burragorang Escarpment Forest (DSF p88).

A total of 547 exotic species was recorded in the 8 535 classified survey sites, which represents approximately 25% of the introduced flora of NSW (NSW DEC 2004a). The number of exotic species recorded is likely to be an underestimate of the total introduced flora within the study area because highly disturbed and weed infested areas were under-sampled in the survey. Four exotic species were recorded in more than 5% of all samples. They were *Hypochaeris radicata* (21%), *Cirsium vulgare* (9%), *Senecio madagascariensis* (5%) and *Plantago lanceolata* (6%). The highest frequency and diversity of exotic species were recorded in grassy woodlands and riparian vegetation on clay-loam soils of both the Cumberland Plain and the tablelands. Riverbank Forest (FOW p32) recorded the highest number of exotic species (175) and contained exotics in 95% of its samples. Conversely, heathlands and woodlands on shallow, low nutrient sandstone soils had the fewest exotic species, with none recorded in 27 of these assemblages.

Coverage of Sampling

The average density of sampling across the region represents about one site for every 3 km^2 of native vegetation. Despite the emphasis on gap-filling in regional scale surveys (Keith & Bedward 1999, Tindall *et al.* 2004), the distribution of samples remains relatively uneven (Fig. 4) due to the concentration of samples produced by more localised surveys (e.g. Royal National Park – Illawarra, Coolangubra – Nalbaugh). Sampling intensity was lowest in some less accessible areas of the Blue Mountains and Morton Plateau; the upper Tuross and Deua River catchments; and some heavily cleared parts of the southern tablelands.

The distribution of samples among classes of land tenure was roughly proportional to class area, although the number of samples located on conservation reserves was disproportionably high at the expense of those on freehold land (Table 5). The proportional distribution of samples

Table 5: Distribution of land, native vegetation and survey effort by tenure type within the study area.

Tenure class:	Crown	Leasehold	Freehold	Reserve	State Forests
Area of land (ha)	188928 (5%)	52049 (1%)	2045218 (51%)	1101095 (28%)	595087 (15%)
Area of native vegetation (ha)	168577 (6%)	44753 (2%)	818301 (31%)	1074166 (41%)	534581 (20%)
Number of samples	574 (7%)	52 (1%)	3001 (36%)	3368 (40%)	1192 (14%)

Table 6: Inferred relationships between vegetation communities described in Appendix 3 and Threatened Ecological Communities listed under NSW or Commonwealth legislation. The inferred relationships are indicative only. The legal definitions of EECs are provided by the Final Determinations under the respective Acts and decisions relating to whether any particular area of vegetation constitutes a TEC should be based on field inspection and comparison with the Final Determination.

Endangered Ecological Communities listed under the TSC Act 1995	Corresponding Map Unit Name	Corresponding Map Unit	Relationship between EEC and corresponding map unit/s
Agnes Banks Woodland in the Sydney Basin Bioregion	Agnes Banks Woodland	DSF p239	EEC is equivalent to DSF p239
Bangalay Sand Forest	Coastal Sand Forest	DSF p64	EEC is included within the broader DSF p64
Blue Gum High Forest (Critically Endangered)	Blue Gum High Forest	WSF p153	EEC is equivalent to WSF p153
Blue Mountains Shale Cap Forest in the Sydney Basin Bioregion	Shale-Basalt Sheltered Forest	WSF p168	EEC is included within the broader WSF p168
Brogo Wet Vine Forest	Brogo Wet Vine Forest	GW e18	EEC is equivalent to GW e18
Castlereagh Swamp Woodland Community	Castlereagh Swamp Woodland	DSF p4	EEC is equivalent to DSF p4
Coastal salt marsh in the NSW North Coast, Sydney Basin and South East Corner bioregions	Estuarine Salt marsh	SL p509	SL p509 is included within this broader EEC
Cooks River/ Castlereagh Ironbark Forest in the Sydney Basin Bioregion	Castlereagh Ironbark Forest	DSF p1	EEC is equivalent to DSF p1
Cumberland Plain Woodland (critically endangered)	Cumberland Shale Hills Woodland + Cumberland Shale Plains Woodland	GW p28 + GW p29	EEC is equivalent to GW p28 and GW p29 combined
Dry Rainforest of the South East Forests in the South East Corner Bioregion	Southeast Dry Rainforest	RF e1	EEC is equivalent to RF e1
Duffys Forest Ecological Community in the Sydney Basin Bioregion	Sydney Shale-Ironstone Cap Forest	DSF p143	EEC is included within the broader DSF p143
Eastern Suburbs Banksia Scrub in the Sydney Basin Bioregion	Eastern Suburbs Banksia Scrub	HL p563	HL p563 is equivalent to this EEC
Elderslie Banksia Scrub Forest	not sampled or described	DSF p463	EEC is equivalent to DSF p463
Freshwater Wetlands on Coastal Floodplains of the NSW North Coast, Sydney Basin and Southeast Corner bioregions	Coastal Freshwater Lagoon (part) + Floodplain Wetlands	FrW p313 + FoW e60	EEC includes occurrences of FRW p313 on floodplains and occurrences of FoW e60 that are not dominated by eucalypts or Angophora
Illawarra Lowlands Grassy Woodland in the Sydney Basin Bioregion	South Coast Lowland Swamp Woodland + South Coast Grassy Woodland	GW p3 + GW p34	EEC is included within two broader map units, GW p3 and GW p34
Illawarra Subtropical Rainforest in the Sydney Basin Bioregion	Subtropical Dry Rainforest (part) + Subtropical Complex Rainforest (part)	RF p111+ RF p112	EEC is included within two broader map units, RF p111 and RF p112
Kurnell Dune Forest in the Sutherland Shire and City of Rockdale	Coastal Sand Forest	DSF p64	EEC is included within the broader DSF p64
Littoral Rainforest in the NSW North Coast, Sydney Basin and South East Corner bioregions	Temperate Littoral Rainforest + Littoral Thicket (part)	RF p210 + HL p63	RF p210 is included within this broader EEC. Examples of HL p63 occurring in sheltered locations with high rainfall may be included in the EEC, particularly when fire has been excluded for long periods.
Lowland Grassy Woodland in the South East Corner bioregion	Southeast Lowland Grassy Woodland	GW e20p229	Within the SEC bioregion this EEC is equivalent to GW e20p229
Maroota Sands Swamp Forest	Sydney Swamp Forest	FoW p44	EEC is included within FoW p44
Melaleuca armillaris Tall Shrubland in the Sydney Basin Bioregion	Basalt Hilltop Scrub	HL p46	EEC is included within HL p46
Milton Ulladulla Subtropical Rainforest in the Sydney Basin Bioregion	Subtropical Dry Rainforest (part) + Subtropical Complex Rainforest (part)	RF p111 + RF p112	EEC is included within two broader map units: RF p111 and small outlying patches of RF p112
Moist Shale Woodland in the Sydney Basin Bioregion	Cumberland Moist Shale Woodland	GW p514	EEC is equivalent to GW p514

Endangered Ecological Communities listed under the TSC Act 1995	Corresponding Map Unit Name	Corresponding Map Unit	Relationship between EEC and corresponding map unit/s
Montane Peatland and Swamp of the New England Tableland, NSW North Coast, Sydney Basin, South East Corner, South Eastern Highlands and Australian Alps bioregions	Riparian Herbfield + Tableland Swamp Meadow + Tableland Bog (part) + Sub-Alpine Bog	FrW p55 + FrW p57 + FrW p53 + FrW e59	EEC includes FrW p55, FrW p57, FrW e59 and occurrences of FrW p53 with few sclerophyll taxa
Mount Gibraltar Forest in the Sydney Basin Bioregion	Southern Highlands Basalt Forest (part) + High Range Sheltered Forest (part)	WSF p266 + WSF p66	EEC is included within the broader WSF p266, and may match variants of the broader WSF p66 where this unit grades into WSF p266
O'Hares Creek Shale Forest	Sydney Shale-Ironstone Cap Forest	DSF p143	EEC is included within the broader DSF p143
Pittwater Spotted Gum Forest	Illawarra Gully Wet Forest	WSF p99	EEC is local occurrence within the broader WSF p99
River Flat Eucalypt Forest on Coastal Floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions (incorporating the previously listed Sydney Coastal River-flat Forest)	Southeast Floodplain Wetlands + Cumberland River Flat Forest + Floodplain Swamp Forest + South Coast River Flat Forest + Burragorang River Flat Forest	FoW e60 + FoW p33+ FoW p105 + FoW p30+ FoW p31	EEC includes those parts of FOW p33, FOW p105, FOW p30, FOW p31 and FOW e60 that are dominated by eucalypts or Angophoras
Robertson Basalt Tall Open-forest in the Sydney Basin Bioregion	Southern Highlands Basalt Forest (part)	WSF p266	EEC is included within the broader WSF p266
Robertson Rainforest in the Sydney Basin Bioregion	Yarrawa Temperate Rainforest	RF p516	EEC is equivalent to RF p516
Shale / Sandstone Transition Forest	Cumberland Shale Sandstone Transition Forest	GW p2	EEC is equivalent to GW p2
Shale Gravel Transition Forest in the Sydney Basin Bioregion	Castlereagh Shale-Gravel Transition Forest	DSF p502	EEC is equivalent to DSF p502
Southern Highlands Shale Woodlands in the Sydney Basin Bioregion	Southern Highlands Shale Woodlands	WSF p268	EEC is equivalent to WSF p268
Southern Sydney Sheltered Forest on Transitional Sandstone Soils in the Sydney Basin	Coastal Sandstone Gully Forest	DSF p140	EEC is included within the broader DSF p140
Sun Valley Cabbage Gum Forest in the Sydney Basin Bioregion	Mapped as an outlier of Burragorang River Flat Forest	FoW p31	EEC possibly included within FoW p31, but relationship uncertain due to disturbed condition of site
Swamp Oak Floodplain Forest of the NSW North Coast, Sydney Basin and South East Corner bioregions	Floodplain Swamp Forest + Estuarine Fringe Forest + Estuarine Creekflat Scrub	FoW p105 + FoW p106 + FoW p107	EEC includes FoW p105, FoW p106 and FoW p107
Swamp Sclerophyll Forest on Coastal Floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions (incorporating the formerly listed Sydney Coastal Estuary Swamp Forest Complex in the Sydney Basin Bioregion)	Sydney Swamp Forest + Coastal Sand Swamp Forest	FoW p44 + FoW p45	EEC includes FoW p44 and FoW p45
Sydney Freshwater Wetlands in the Sydney Basin Bioregion	Coastal Freshwater Lagoon (part)	FrW p313	EEC includes occurrences of FrW p313 on sandplains.
Sydney Turpentine-Ironbark Forest	Sydney Turpentine Ironbark Forest	WSF p87	EEC is equivalent to WSF p87
Tableland Basalt Forest in the Sydney Basin and South Eastern Highlands Bioregions	Tableland Basalt Forest	GW p20	EEC includes GW p20
Themeda Grassland on Sea cliffs and Coastal Headlands	Headland Grassland	GL p434	GL p434 is included within this broader EEC
Umina Coastal Sand plain Woodland	Coastal Sand Forest	DSF p64	EEC is included within the broader DSF p64
Western Sydney Dry Rainforest in the Sydney Basin Bioregion	Grey Myrtle Dry Rainforest	RF p39	EEC is included within the broader RF p39
White Box Yellow Box Blakely's Red Gum Woodland	Tableland Grassy Box-Gum Woodland + Wollondilly-Cox-Shoalhaven Gorge Woodland + Tableland Granite Grassy Woodland	GW p24 + DSF p35 + GW p420	Some occurrences of these three map units are likely to match this broad EEC

Vulnerable Ecological Communities listed under the TSC Act 1995	Corresponding Map Unit Name	Corresponding Map Unit	Relationship between VEC and corresponding map unit/s
Blue Mountains Swamps in the Sydney Basin bioregion	Blue Mountains - Shoalhaven Hanging Swamps	FRW p130	VEC includes parts of FRW p130 within the Hawkesbury-Nepean catchment

Endangered Ecological Communities listed under the EPBC Act 1999	Corresponding Map Unit Name	Corresponding Map Unit	Relationship between EEC and corresponding map unit
Blue Gum High Forest of the Sydney Basin Bioregion (Critically Endangered)	Blue Gum High Forest	WSF p153	EEC is equivalent to WSF p153
Cumberland Plain Woodlands	Cumberland Shale Hills Woodland + Cumberland Shale Plains Woodland	GW p28 + GW p29	EEC is equivalent to GW p28 and GW p29 combined
Eastern Suburbs Banksia Scrub of the Sydney Region	Eastern Suburbs Banksia Scrub	HL p563	HL p563 is equivalent to this EEC
Littoral Rainforest and Coastal Vine Thickets of Eastern Australia	Temperate Littoral Rainforest + Littoral Thicket (part)	RF p210 + HL p63	RF p210 is included within this broader EEC. Examples of HL p63 in sheltered locations with high rainfall may be included in the EEC, particularly when long unburnt.
Natural Temperate Grasslands of the Southern Tablelands of NSW and the ACT	Monaro Grassland + Frost Hollow Grassy Woodland + Tableland Grassy Box-Gum Woodland + Tableland Flats Grassland + Tableland Granite Grassy Woodland	GL e23A + GW p22 + GW p24 + GL p257 + GW p420	These Map Units include areas of low tree density that match the description of this EEC
Shale/Sandstone Transition Forest	Cumberland Shale Sandstone Transition Forest	GW p2	EEC is equivalent to GW p2
Temperate Highland Peat Swamps on Sandstone	Southeast Sub-Alpine Bog + Tableland Bog + Tableland Swamp Meadow + Blue Mountains – Shoalhaven Hanging Swamps	FrW e59 + FrW p53 + FrW p57 + FrW p130	FrW e59, FrW p53, FrW p57 and FrW p130 form part of this EEC
Turpentine-Ironbark Forest in the Sydney Basin Bioregion (Critically Endangered)	Sydney Turpentine Ironbark Forest	WSF p87	EEC is equivalent to WSF p87
White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and derived native grassland (Critically Endangered)	No Map Units are directly equivalent to this EEC as it is described; however, some areas of Map Units GW p24 (Tableland Grassy Box-Gum Woodland) and GW p420 (Tableland Granite Grassy Woodland) may match the EEC description, particularly along the western edge of the study area	GW p24 + GW p420	No Map Units are directly equivalent to this EEC as described, however some areas of GW p24 and GW p420 may match the EEC description

Table 7: Summary of correspondence between the current classification compared to previous classifications covering small subsets of the study area. Correspondence was the number (proportion) of units in the previous classification that had equivalent units in the current classification within the common area.

Previous Study	Common Area (ha)	No. Sites classified in area of overlap	No. Sites classified in the current study	No. Units (previous study)	No. Units (current study)	Correspondence of previous classification to current classification
Southern CRA (Gellie 2005)	2129675	1366	3002	92	133	24 (26%)
Illawarra (NPWS 2002)	38398	182	176	33	22	31 (94%)
Warragamba (NPWS 2003a)	260708	825	788	71	51	62 (87%)
Cumberland Plain (Tozer 2003)	336946	735	735	24	22	24 (100%)

Table 8: Summary of relationships between units in the current study and NSW Formations and Classes (Keith 2004), P5MA (Tindall *et al.* 2004), Eden CRA (Keith & Bedward 1999) and Southern CRA (Gellie 2005).

Abbreviations:
DSFg – Dry Sclerophyll Forest – grassy subformation
DSFs – Dry Sclerophyll Forest – shrubby subformation
FoW – Forested Wetlands
FrW – Freshwater Wetlands
GL – Grasslands
GW – Grassy Woodlands
HL – Heathlands
RF – Rainforest
SL – Saline Wetlands
WSFg – Wet Sclerophyll Forests – grassy subformation
WSFs – Wet Sclerophyll Forests – shrubby subformation

Map code	**Unit name**	**Formation**	**Class**	**P5MA unit**	**Eden units**	**SCRA FEs**	**Area Extant (ha):**	**Est. % remaining**	**Area in conservation reserves (ha):**	**Est. % of pre-clearing area in conservation reserves:**
e1	Southeast Dry RF	RF	Dry RF	–	1	–	270	40–55	100	15–30
e3	Rocky Tops Dry Scrub Forest	DSFs	South East DSF	–	2, 3	–	1300	>95	1200	80–90
e4	Brogo Shrub Forest	DSFs	Southern Wattle DSF	–	4	–	5800	>90	4300	70–80
e6e7	Southeast Warm Temperate RF	RF	Southern Warm Temperate RF	–	6, 7	g165	9500	>90	5200	50–60
e9	Southeast High Mountain Wet Layered Forest	WSFs	Southern Escarpment WSF	–	9	–	1800	75–85	1600	65–75
e10	Southeast Mountain Wet Layered Forest	WSFs	Southern Escarpment WSF	–	10	–	17500	85–95	9900	45–55
e11	Tantawangalo Wet Shrub Forest	WSFs	Southern Escarpment WSF	–	11	–	800	>95	740	>90
e12	Mountain Wet Fern Forest	WSFs	Southern Escarpment WSF	70	12	–	48300	>95	36300	70–80
e13	Southeast Hinterland Wet Fern Forest	WSFs	South Coast WSF	–	13	–	26900	>90	14600	45–55
e14	Southeast Hinterland Wet Shrub Forest	WSFs	South Coast WSF	–	14	–	25500	>90	9600	30–40
e15	Southeast Mountain Wet Herb Forest	WSFg	Southern Escarpment WSF	–	15	–	29800	70–80	15900	35–45
e17	Southeast Flats Swamp Forest	FoW	Temperate Swamp Forests	–	17, part 58	–	3900	80–90	1500	20–35
e18	Brogo Wet Vine Forest	GW	Coastal Valley GW	–	18	part g49	5200	50–65	1400	10–20
e19	Bega Wet Shrub Forest	DSFg	Southern Hinterland DSF	–	19, W6	part g49	23600	35–50	6600	5–15
e20p229	Southeast Lowland Grassy Woodland	GW	Coastal Valley GW	229, part 34	20,21	g54	14000	10–25	780	<5
e23A	Monaro Grassland	GL	Temperate Montane Grasslands	–	23a	–				
e24	Southeast Sub-alpine Dry Shrub Forest	GW	Subalpine woodlands	–	24	part g64	6200	50–60	2000	10–20
e25	Southeast Sandstone Dry Shrub Forest	DSFs	South East DSF	–	25	–	820	65–75	720	60–70
e26	Southeast Tableland Dry Shrub Forest	DSFs	South East DSF	–	26	part g64	15000	60–70	5700	20–30
e27	Waalimma Dry Grass Forest	DSFg	Southern Hinterland DSF	–	27	–	1300	>95	300	15–25
e28	Wog Wog Dry Grass Forest	DSFg	Southern Hinterland DSF	–	28	–	920	65–75	880	60–70
e29	Nalbaugh Dry Grass Forest	DSFg	Southern Hinterland DSF	–	29	–	1800	70–80	700	25–35
e30	Wallagaraugh Dry Grass Forest	DSFg	Southern Hinterland DSF	–	30	–	800	50–60	350	20–30

Map code	Unit name	Formation	Class	P5MA unit	Eden units	SCRA FEs	Area Extant (ha):	Est. % remaining	Area in conservation reserves (ha):	Est. % of pre-clearing area in conservation reserves:
e31	Southeast Hinterland Dry Grass Forest	DSFg	Southern Hinterland DSF	–	31	–	27100	80–90	16500	45–55
e33	Southeast Coastal Range Dry Shrub Forest	DSFs	South East DSF	–	part 33	–	16300	>95	9700	55–65
e34	Southeast Coastal Gully Shrub Forest	WSFs	South Coast WSF	–	34	–	22800	>85	6900	25–35
e35	Southeast Escarpment Dry Grass Forest	DSFg	Southern Hinterland DSF	–	35	part g47	22600	65–75	9200	20–30
e37	Southeast Lowland Gully Shrub Forest	WSFs	South Coast WSF	–	37	–	13700	>95	4700	30–40
e38	Far Southeast Riparian Scrub	FoW	Eastern Riverine Forests	–	38	–	420	>90	290	55–65
e39	Bega-Towamba Riparian Scrub	FoW	Eastern Riverine Forests	–	39	–	340	<30	40	<10
e42	Southeast Inland Intermediate Shrub Forest	WSFs	South Coast WSF	–	42	–	21400	>95	5700	20–30
e43	Southeast Mountain Sandstone Shrub Forest	DSFs	South East DSF	–	43	–	2500	>95	2300	>90
e44	Southeast Foothills Dry Shrub Forest	DSFs	South East DSF	–	44	–	3100	>90	2300	65–75
e45	Southeast Mountain Dry Shrub Forest	DSFs	South East DSF	–	45	–	1800	>90	1100	50–60
e46a	Timbillica Dry Shrub Forest	DSFs	South East DSF	–	46a	–	22800	>95	3500	10–20
e46b	Southeast Lowland Dry Shrub Forest	DSFs	South East DSF	–	46b	–	14300	>90	6900	40–50
e47	Eden Dry Shrub Forest	DSFs	South East DSF	–	47	–	17100	>95	12300	65–75
e48	Mumbulla Dry Shrub Forest	DSFs	South East DSF	–	48	–	4500	>95	3500	70–80
e49	Southeast Coastal Dry Shrub Forest	DSFs	South East DSF	–	49	–	31800	>95	8000	20–30
e50	Genoa Dry Shrub Forest	DSFs	South East DSF	–	50	–	3000	>95	2100	55–70
e51	Southeast Rhyolite Rock Scrub	HL	Southern Volcanic Scrubs	–	51	–	50	>95	40	75–85
e52	Southeast Mountain Rock Scrub	HL	Southern Volcanic Scrubs	–	52	–	160	>95	160	>90
e53	Southern Montane Heath	HL	Southern Montane Heaths	123	53	g134, g135	6700	>95	3600	50–65
e54	Mt Nadgee Heath	HL	South Coast Heaths	–	54	–	370	>95	370	100
e55	Southeast Coastal Lowland Heath	HL	South Coast Heaths	–	55	–	1900	>90	1700	75–90
e56	Southeast Hinterland Heath	FrW	Coastal Heath Swamps	–	56	–	360	>90	80	15–25
e57	Southeast Lowland Swamp	FrW	Coastal Heath Swamps	–	57	–	1700	>70	1000	50–65
e59	Southeast Sub-alpine Bog	FrW	Montane Bogs and Fens	–	59	g123	2700	50–70	880	15–25
e60	Southeast Floodplain Wetlands	FoW	Coastal Floodplain Wetlands	–	60	–	1800	15–25	100	<5
e61	Coastal Foredune Scrub	DSFs	South Coast Sands DSF	65	61	–	3100	35–50	1700	25–35
e62	Beach Strand Grassland	GL	Maritime Grasslands	–	62	–				
e65	River Mangrove	SL	Mangrove Swamps	–	65	–	550	#N/A	210	<5
e67	Seagrass Meadow (Halophila)	SL	Seagrass Meadows	–	67	–	610	<50	60	5–10
e68	Seagrass Meadow (Posidonia)	SL	Seagrass Meadows	–	68	–	260	<50	20	<5

Map code	**Unit name**	**Formation**	**Class**	**P5MA unit**	**Eden units**	**SCRA FEs**	**Area Extant (ha):**	**Est. % remaining**	**Area in conservation reserves (ha):**	**Est. % of pre-clearing area in conservation reserves:**
e69	Seagrass Meadow (Ruppia)	SL	Seagrass Meadows	–	69	–	150	<50	60	5–10
e70	Seagrass Meadow (Zostera)	SL	Seagrass Meadows	–	70	–	1400	<50	80	<5
e81	Wadbilliga Dry Shrub Forest	DSFs	South East DSF	–	W1	–	6600	>95	6600	>95
e83	Wadbilliga Heath Forest	HL	Southern Montane Heaths	–	W3	–	1600	>95	1600	>95
e85	Wadbilliga Gorge Dry Forest	DSFs	South East DSF	–	W5	–	16000	>85	11000	55–65
e32A	Deua-Brogo Foothills Dry Shrub Forest	DSFs	South East DSF	part 90	part 32	-	42200	>95	27700	60-70
e32B	Far South Coastal Foothills Dry Shrub Forest	DSFs	South East DSF	-	part 32, part 33	g6	14000	>90	4700	25-35
m15	Eden Shrubby Swamp Woodland	FoW	Temperate Swamp Forests	-	-	-	0	>70	0	>80
m68	Southeast Tablelands Grassy Wetlands Complex	GL	Temperate Montane Grasslands	-	-	-				
m83	South Coast Headland Scrub	HL	Coastal Headland Heaths	-	-	-				
n183	South Coast Hinterland Wet Forest	WSFs	South Coast WSF	part 100 part 103	-	-	69400	>95	30300	40-50
n184	Clyde-Tuross Hinterland Forest	WSFs	Southern Lowland WSF	part 100	-	-	19300	>95	7400	30-40
p1	Castlereagh Ironbark Forest	DSFg	Cumberland DSF	1	-	-				
p2	Cumberland Shale Sandstone Transition Forest	GW	Coastal Valley GW	2	-	-	9700	20-40	260	<2
p3	South Coast Lowland Swamp Woodland	GW	Coastal Valley GW	3	-	-	1100	5-15	90	<1
p4	Castlereagh Swamp Woodland	DSFg	Sydney Sand Flats DSF	4	-	-	610	55-70	120	5-15
p5	Burragorang Hillslope Forest	DSFg	Central Gorge DSF	5	-	-	20700	75-90	20400	70-90
p6	Burragorang-Nepean Hinterland Woodland	DSFg	Sydney Sand Flats DSF	6	-	-	960	80-90	550	40-55
p7	Castlereagh Scribbly Gum Woodland	DSFg	Sydney Sand Flats DSF	7	-	-	3100	50-70	390	<10
p8	Tableland Ridge Forest	DSFs	South East DSF	8	-	-	44500	80-90	25600	40-60
p9	Tableland Low Woodland	DSFs	Southern Tableland DSF	9	-	-	36700	40-60	4400	<10
p10	Eastern Tablelands Dry Forest	DSFs	South East DSF	10	-	g15	48000	60-75	11200	10-25
p11	Elevated Gorge Forest	DSFg	Central Gorge DSF	11	-	g16	34600	80-95	14600	30-45
p14	Western Tablelands Dry Forest	DSFs	Southern Tableland DSF	14	22b	-	121600	45-65	24500	<15
p15	Braidwood Dry Forest	DSFs	Southern Tableland DSF	15	-	-	35200	45-65	2800	<10
p17	Lithgow-Abercrombie Grassy Forest	GW	Southern Tableland GW	17	-	-	100	35-55	0	0
p19	Abercrombie-Tarlo Footslope Woodland	GW	Southern Tableland GW	19	-	part g90	5200	70-85	1700	15-35
p20	Tableland Basalt Forest	GW	Tableland Clay GW	20	-	-	10700	5-20	280	<2
p22	Frost Hollow Grassy Woodland	GW	Subalpine Woodlands	22	part 23b	-	14100	5-20	680	<2
p23	Tableland Hills Grassy Woodland	GW	Southern Tableland GW	23	-	-	18800	20-40	710	<2

Map code	Unit name	Form-ation	Class	P5MA unit	Eden units	SCRA FEs	Area Extant (ha):	Est. % remain-ing	Area in conservation reserves (ha):	Est. % of pre-clearing area in conservation reserves:
p24	Tableland Grassy Box-Gum Woodland	GW	Southern Tableland GW	24	-	-	17900	10-25	10	<1
p27	Bungonia Slates Woodland	DSFg	Central Gorge DSF	27	-	-	21200	85-95	9200	30-50
p28	Cumberland Shale Hills Woodland	GW	Coastal Valley GW	28	-	-	4400	10-25	210	<2
p29	Cumberland Shale Plains Woodland	GW	Coastal Valley GW	29	-	-	6800	5-25	560	<2
p30	South Coast River Flat Forest	FoW	Coastal Floodplain Wetlands	30	-	-	8400	50-65	1600	<15
p31	Burragorang River Flat Forest	FoW	Eastern Riverine Forests	31	-	-	1900	>95	1800	>90
p32	Riverbank Forest	FoW	Eastern Riverine Forests	32	40	-	9400	60-85	3900	25-45
p33	Cumberland River Flat Forest	FoW	Coastal Floodplain Wetlands	33	-	-	5300	5-20	150	<2
p34	South Coast Grassy Woodland	GW	Coastal Valley GW	part 34	-	-	3100	15-30	180	<2
p35	Wollondilly-Cox-Shoalhaven Gorge Woodland	DSFg	Central Gorge DSF	35	-	-	41800	50-65	14100	20-30
p36	Kowmung-Wollondilly Gorge Forest	DSFg	Central Gorge DSF	36	-	-	26200	>95	24600	>85
p37	Kowmung-Wollondilly Grassy Gorge Woodland	DSFg	Central Gorge DSF	37	-	-	37100	>90	31700	70-90
p38	Grey Myrtle Dry RF	RF	Dry RF	38	-	-	6550	75-85	5600	55-75
p39	Western Sydney Dry Rainforest	RF	Dry RF	-	-	-	350	25-50	<20	<3
p40	Temperate Dry RF	RF	Dry RF	40	-	-	7500	>90	3500	40-50
p44	Sydney Swamp Forest	FoW	Coastal Swamp Forests	44	-	-	160	70-85	20	<10
p45	Coastal Sand Swamp Forest	FoW	Coastal Swamp Forests	45	-	-	1400	50-70	370	5-25
p46	Basalt Hilltop Scrub	HL	Southern Volcanic Scrubs	46	-	-	390	<30	0	<1
p50	Sandstone Cliff Soak	HL	Sydney Montane Heaths	50	-	-		#N/A	0	#N/A
p51	Tableland Lacustrine Herbfield	FrW	Montane Lakes	51	-	-	2600	<15	0	<1
p53	Tableland Bog	FrW	Montane Bogs and Fens	53	-	-	730	65-85	170	5-25
p54	Tableland Swamp Forest	FoW	Temperate Swamp Forests	54	-	-	1700	20-50	1100	50-70
p55	Riparian Herbfield	FrW	Montane Bogs and Fens	55	-	-		#N/A	0	#N/A
p56	Shoalhaven Riparian Scrub	FrW	Montane Bogs and Fens	56	-	-	1300	>80	30	<5
p57	Tableland Swamp Meadow	FrW	Montane Bogs and Fens	57	part 58	-	3800	15-25	470	<5
p58	Sandstone Riparian Scrub	FoW	Eastern Riparian Scrubs	58	-	-	2900	>90	1300	30-50
p63	Littoral Thicket	HL	Littoral RF	63	-	-	1800	50-70	1100	20-40
p64	Coastal Sand Forest	DSFs	South Coast Sands DSF	64	36	-	11200	50-70	6500	20-40
p66	Highland Range Sheltered Forest	WSFg	Southern Tableland WSF	66	-	-	18500	>90	12500	55-75
p68	Nepean Shale Cap Forest	WSFg	Northern Hinterland WSF	68	-	-	660	>90	0	0

Map code	Unit name	Formation	Class	P5MA unit	Eden units	SCRA FEs	Area Extant (ha):	Est. % remaining	Area in conservation reserves (ha):	Est. % of pre-clearing area in conservation reserves:
p72	Blue Mountains Basalt Forest	WSFs	Southern Escarpment WSF	72	-	-	480	50-70	160	10-30
p73	Cool Montane Wet Forest	WSFs	Southern Tableland WSF	part 73	-	-	62600	70-90	44200	35-55
p76	Moist Montane Sandstone Forest	DSFs	Sydney Montane DSF	76	-	-	4800	>95	4500	>85
p78	Southern Escarpment Ash Forest	WSFg	Montane WSF	78	41, W2	-	4400	>95	4100	>95
p84	Ettrema Gorge Forest	DSFg	Central Gorge DSF	84	-	-	8800	>90	7400	65-85
p85	Currambene-Batemans Lowlands Forest	DSFg	South East DSF	85	-	-	24700	55-75	5800	5-20
p86	Murramarang Lowlands Forest	WSFg	Southern Lowland WSF	86	-	-	7100	65-80	1500	5-15
p87	Sydney Turpentine Ironbark Forest	WSFg	Northern Hinterland WSF	87	-	-	2300	<10	250	<2
p88	Burragorang Escarpment Forest	DSFg	Central Gorge DSF	88	-	-	13200	>95	12700	>90
p89	Batemans Bay Foothills Dry Forest	DSFs	South East DSF	89	-	-	67100	>90	35200	45-65
p90	Batemans Bay Cycad Forest	WSFg	Southern Lowland WSF	part 90	-	-	56100	>85	14000	15-25
p91	Clyde-Deua Open Forest	DSFs	South East DSF	91	part 33	-	34100	>95	24500	65-75
p95	Southern Turpentine Forest	WSFg	Southern Lowland WSF	95	-	-	62400	>85	38300	45-65
p98	Clyde-Deua Ridgetop Forest	DSFs	South East DSF	98	-	-	30400	>90	23000	65-85
p99	Illawarra Gully Wet Forest	WSFs	North Coast WSF	99	-	-	7100	50-70	1900	5-20
p100	Escarpment Foothills Wet Forest	WSFg	South Coast WSF	part 100	-	-	31500	>90	12000	25-40
p102	Lower Blue Mountains Wet Forest	WSFs	North Coast WSF	102	-	-	23400	>95	19800	75-90
p103	Clyde Gully Wet Forest	WSFg	Southern Lowland WSF	part 103	-	-	17900	>90	6600	25-40
p104	Southern Lowland Wet Forest	WSFg	Southern Lowland WSF	104	-	-	25900	>85	9200	25-45
p105	Floodplain Swamp Forest	FoW	Coastal Floodplain Wetlands	105	-	-	2400	5-20	480	<5
p106	Estuarine Fringe Forest	FoW	Coastal Floodplain Wetlands	106	-	-	840	5-20	140	<5
p107	Estuarine Creekflat Scrub	FoW	Coastal Floodplain Wetlands	107	63	-	3700	70-85	1200	15-30
p109	Estuarine Mangrove Forest	SL	Mangrove Swamps	109	66	-	3700	50-75	740	<15
p110	Warm Temperate Layered Forest	WSFs	North Coast WSF	110	-	-	21500	55-70	4500	5-20
p111	Subtropical Dry RF	RF	Subtropical RF	111	-	part g167	2400	10-20	130	<2
p112	Subtropical Complex RF	RF	Subtropical RF	112	-	-	4100	50-65	440	<10
p113	Coastal Warm Temperate RF	RF	Northern Warm Temperate RF	113	-	g166	15200	85-95	7900	35-50
p114	Sandstone Scarp Warm Temperate RF	RF	Northern Warm Temperate RF	114	-	-	6800	>95	5900	80-95
p116	Intermediate Temperate RF	RF	Southern Warm Temperate RF	part 116	-	part g167	3000	75-90	1600	35-50
p117	Coastal Sandstone Plateau Heath	HL	Sydney Coastal Heaths	117	-	-	16100	>90	11300	50-70

Map code	Unit name	Formation	Class	P5MA unit	Eden units	SCRA FEs	Area Extant (ha):	Est. % remaining	Area in conservation reserves (ha):	Est. % of pre-clearing area in conservation reserves:
p120	Kanangra-Ti Willa Montane Heath	HL	Sydney Montane Heaths	120	-	-	1100	>95	1100	>95
p121	Loombah Plateau Heath	HL	Sydney Montane Heaths	121	-	-	340	>95	330	>95
p122	Morton Mallee-Heath	HL	Sydney Montane Heaths	122	-	-	37600	>95	33700	80-95
p124	Blue Mountains Heath	HL	Sydney Montane Heaths	124	-	-	7900	>95	6200	70-85
p125	Morton Rock Plate Heath	HL	Sydney Montane Heaths	125	-	-	4700	>95	4200	80-95
p126	Coastal Rock Plate Heath	HL	Sydney Coastal Heaths	126	-	-	260	>95	50	10-30
p127	Sandstone Headland Scrub	HL	Sydney Coastal Heaths	127	-	-	290	>95	200	60-80
p129	Coastal Upland Swamp	FrW	Coastal Heath Swamps	129, 303	-	part g141	4800	>90	1300	15-30
p130	Blue Mountains - Shoalhaven Hanging Swamps	FrW	Coastal Heath Swamps	130	-	part g141	5000	>95	3500	60-75
p131	Coastal Sandstone Ridgetop Woodland	DSFs	Sydney Coastal DSF	131	-	part g136	111000	75-90	49900	25-45
p136	Blue Mountains Ridgetop Forest	DSFs	Sydney Montane DSF	136	-	-	28800	80-95	21200	55-70
p139	Coastal Sandplain Heath	HL	Wallum Sand Heaths	139	-	part g136	1000	>90	530	20-40
p140	Coastal Sandstone Gully Forest	DSFs	Sydney Coastal DSF	140	-	-	24400	70-85	7700	15-35
p141	Budderoo-Morton Plateau Forest	DSFs	Sydney Montane DSF	141	-	-	5500	80-95	5200	70-90
p142	Hinterland Sandstone Gully Forest	DSFs	Sydney Hinterland DSF	142	-	-	90900	80-95	46800	35-55
p143	Sydney Shale-Ironstone Cap Forest	DSFg	Northern Hinterland WSF	143	-	-	2600	50-70	1600	30-50
p144	Wingecarribee-Burragorang Sandstone Forest	DSFs	Sydney Hinterland DSF	144	-	-	65900	80-95	41700	50-65
p146	Sydney Hinterland Transition Woodland	DSFs	Sydney Hinterland DSF	146	-	-	41800	60-80	13000	10-30
p148	Shoalhaven Sandstone Forest	DSFs	Sydney Coastal DSF	148	-	-	56500	80-95	30900	40-55
p149	Morton Sandstone Heath Woodland	DSFs	Sydney Montane DSF	149	-	-	18500	>90	16600	80-95
p153	Blue Gum High Forest	WSFs	North Coast WSF	153	-	-	180	<10	20	<2
p168	Shale-Basalt Sheltered Forest	WSFs	Southern Tableland WSF	168	-	-	2500	20-35	350	<10
p202	Burragorang Rocky Slopes Woodland	DSFg	Cumberland DSF	202	-	-	2200	45-65	2200	45-55
p210	Temperate Littoral RF	RF	Littoral RF	210	5	-	470	70-90	360	50-65
p219	Wombeyan Caves Woodland	DSFg	Central Gorge DSF	219	-	-	310	60-80	0	<1
p220	Southern Tableland Flats Forest	GW	Tableland Clay GW	220	22a, part 23b	-	58600	10-30	22100	<5
p239	Agnes Banks Woodland	DSFs	Sydney Sand Flats DSF	239	-	-	90	15-25	30	<10
p244	Megalong-Tonalli Sandstone Forest	DSFs	Sydney Hinterland DSF	244	-	-	29500	>90	26300	80-95
p246	Yalwal Shale-Sandstone Transition Forest	DSFs	Sydney Hinterland DSF	246	-	-	21100	>85	15300	55-75
p248	Morton-Budawang Sandstone Woodland	DSFs	Sydney Montane DSF	248	-	-	11600	>90	7700	60-80
p257	Tableland Flats Grassland	GL	Temperate Montane Grasslands	257	-	-	10900	<10	0	0

Map code	Unit name	Formation	Class	P5MA unit	Eden units	SCRA FEs	Area Extant (ha):	Est. % remaining	Area in conservation reserves (ha):	Est. % of pre-clearing area in conservation reserves:
p266	Southern Highlands Basalt Forest	WSFs	Southern Escarpment WSF	266	-	-	2000	20-35	690	<15
p268	Southern Highlands Shale Woodland	WSFg	Southern Tableland WSF	268	-	-	5400	10-25	20	<1
p313	Coastal Freshwater Lagoon	FrW	Coastal Freshwater Lagoons	313	-	-	3700	30-70	480	<15
p314	Budderoo Temperate RF	RF	Northern Warm Temperate RF	314	-	-	400	>95	230	45-65
p317	Southeast Cool Temperate RF	RF	Cool Temperate RF	317, part 116	8	-	3000	>95	2400	80-95
p338	Southern Range Wet Forest	WSFg	Southern Escarpment WSF	338, part 73	16, W4	-	87800	>90	38000	30-40
p343	Araluen Scarp Grassy Forest	DSFg	Southern Hinterland DSF	343	-	-	8800	75-90	2400	15-30
p420	Tableland Granite Grassy Woodland	GW	Southern Tableland GW	420	-	-	8400	20-35	20	<1
p434	Headland Grassland	GL	Maritime Grasslands	434	-	-	30	<30	20	10-20
p463	Elderslie Banksia Scrub	DSFs	Sydney Sand Flats DSF	463	-	-		<15	0	0
p502	Castlereagh Shale-Gravel Transition Forest	DSFg	Cumberland DSF	502	-	-	1700	25-35	230	<10
p509	Estuarine Saltmarsh	SL	Saltmarshes	509	64	-	2200	<50	690	10-30
p514	Cumberland Moist Shale Woodland	GW	Coastal Valley GW	514	-	-	600	25-35	10	<1
p516	Yarrawa Temperate RF	RF	Southern Warm Temperate RF	516	-	-	870	15-30	30	<2
p520	Tableland Swamp Flats Forest	FoW	Temperate Swamp Forests	520	-	-	11000	20-35	2500	<10
p563	Eastern Suburbs Banksia Scrub	HL	Wallum Sand Heaths	563	-	-	250	<10	90	<2
p599	Central Coast Wet Forest	WSFs	North Coast WSF	599	-	-	90	20-35	40	10-25

closely matched the distribution of native vegetation among land tenure classes (Table 5), although the proportion of samples located on freehold land was slightly higher than the proportion of native vegetation occurring there, leaving State Forests proportionally under-sampled (Table 5). Additional sampling carried out during this survey greatly increased the number of samples on freehold tenure. In part of the study area surveyed previously by Gellie (2005), for example, 781 additional quadrats were surveyed on private land, increasing proportional representation of sampling on freehold tenure from 25% to 39%.

Extent, Fragmentation and Structure of Extant Native Vegetation

Sixty six percent (2 657 571 ha) of the study area was mapped as extant native vegetation. Some 97.7% of polygons mapped as extant native vegetation occur as remnants of less than 50 ha (90.0% as remnants less than 10 ha) in a matrix of cleared land. These account for 7.5% of native vegetation in the study area. The majority of these small remnants occur on privately owned lands on the central and southern tablelands and highlands, and in the heavily developed semi-rural and urban areas of the Cumberland Plain and coastal lowlands. Most of the remaining vegetation lies in a large, more or less continuous band of public reserves stretching from the Blue Mountains in the north, along the eastern edge of the tablelands and the coastal ranges to the Victorian border.

Most of the field samples were located in sclerophyll forests dominated by eucalypts, although rainforest formations (RF1, RF2) had high proportional representation. A small proportion of survey sites (5.4%) was located outside of areas mapped as extant native vegetation. Examination of the species composition and structure of these samples showed that many are either in woody remnants below the minimum specifications of the mapping (i.e. 0.5 ha patches, 5% woody crown cover), or in non-woody assemblages of native vegetation. This highlights the limits of the map resolution and the difficulties of interpreting remote imagery to delineate patterns in open woody and non-woody vegetation in landscapes heavily modified by urban and rural development.

Distribution Modelling

Approximately 3 800 decision rules applied to 60 environmental and spatial variables were used to model the spatial distributions of map units over the study area. The most frequently applied spatial variables in the set of decision rules were vegetation structural category, soil landscapes and lithology. The highest-order nodes of the decision tree split the samples into groups based on the most informative regional scale variables. These included northing, annual rainfall, maximum temperature of the warmest period, minimum temperature of the coldest period, parent lithology and elevation. Lower-order splits in the decision tree reflected local variation represented by variables such as soil landscape, vegetation structure, aspect indices, solar radiation, topographic roughness, topographic position and distance to streams. Structurally distinctive vegetation communities such as Heathlands, Rainforests and Saline Wetlands were mapped using rules based on the relevant vegetation structural categories interpreted from remote imagery. Three of the 189 floristic assemblages defined in the cluster analyses could not be mapped because of low sample numbers and the lack of suitable spatial data layers to describe their distributions. These were Riparian Herbfield (FRW p55), Sandstone Cliff Soak (HL p50) and Eden Shrubby Swamp Woodland (FOW m15) all of which are likely to have very restricted distributions.

Endangered Ecological Communities

As of June 2008, 45 ecological communities occurring within the study area were listed as threatened under the NSW TSC Act 1995 (Table 6), of which 42 were Endangered, two were Critically Endangered and one was Vulnerable. Nine communities listed as Endangered or Critically Endangered under the Commonwealth EPBC Act 1999 occur within the study area (Table 6). In addition, seven of the communities identified by this study (SL e65, e67, e68, e69, e70, p109, p509) have legal protection as Protected Marine Vegetation under the *Fisheries Management Act 1994*. Inferred relationships between map units and EECs listed under the TSC Act, and the EPBC Act are shown in Table 6.

Of the 45 threatened ecological communities listed under NSW legislation, five are rainforests, seven are wet sclerophyll forests, eleven are dry sclerophyll forests, eight are grassy woodlands, one is a grassland, two are heathlands, six are forested wetlands, four are freshwater wetlands and one is a saline wetland. These are found primarily around the Sydney metropolitan area, the coastal floodplains and river valleys and throughout the tablelands. Threatened Ecological Communities account for 24% of map units described in this study, but these map units account for only 2% of the extant native vegetation mapped within the study area.

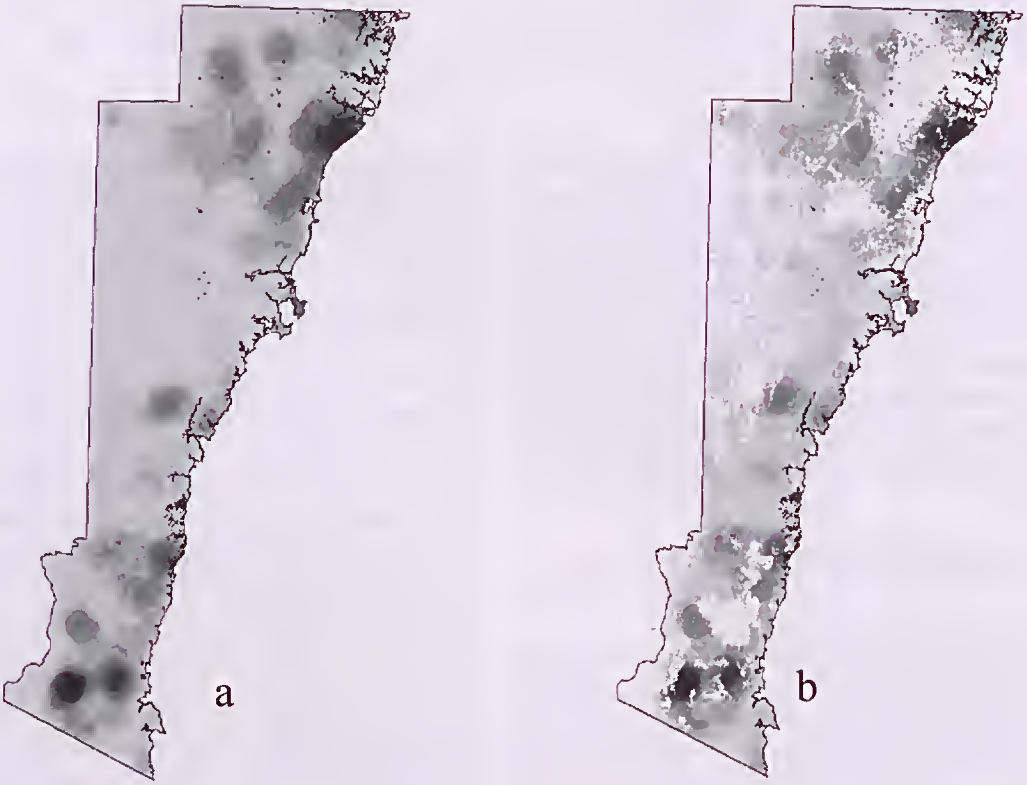


Fig. 4. Relative density of field samples for: a) whole study area; and b) areas of extant vegetation. Darker shading indicates higher density of sampling

Relationships with other classifications

A high proportion (81%) of communities described in the current study had equivalent units in previous classifications of Keith & Bedward (1999) and Tindall *et al.* (2004), indicating the robustness of the classifications. A further 11 were related to units described in both studies and were assigned the unit number from the region contributing the highest number of samples. Five new communities were identified as a result of the inclusion of additional samples located primarily in the geographic gap between the previous surveys of the Eden region (Keith & Bedward 1999) and south coast (Tindall *et al.* 2004) (m15, m68, m83), or through the reinterpretation of existing samples in the broader spatial context (n183, n184). The remaining 20 communities were derived from recombinations of nine units from Tindall *et al.* (2004) and 19 units from Keith & Bedward (1999) primarily in the southern and northern extremities of those study areas, respectively. The alternative groupings of floristic samples produced a more compatible representation of patterns in species composition across the transition zone than the two separate classifications.

There were strong similarities between the classification of this study (Appendix 3) and those of previous studies overlapping a smaller subset of the study area, as indicated by high levels of direct 1:1 correspondence between respective units (Table 7). A high proportion of communities described by Tozer (2003) had equivalent units in the current classification, while a slightly lower proportion of units described by NPWS (2002) and NPWS (2003a) had equivalent units in the current classification. The classification of Gellie (2005) showed moderate levels of correspondence with the current classification, with less than half the units in each classification having equivalent units in the other (Table 8).

Discussion

Methods and Approach

While classifications and maps covering large areas are more likely to give a complete perspective on the distribution and relationships among vegetation communities, these are often perceived as less accurate, less precise and lacking in thematic detail compared to maps of smaller areas. We sought to optimise this trade-off between extent and detail by utilising all available field and linework data from more localised studies and extending common aspects of their methods over a much larger area. Although the current project was nominally conceived as a medium scale (1:100,000) mapping project (Sivertsen & Smith 2001), the scales of interpretation and mapping of compositional patterns aimed to meet the requirements of the legislative and planning framework in NSW (e.g. Threatened Ecological Communities under the TSC Act 1995, native vegetation types under the NV Act 2003). These dictated an approach which essentially replicated the methods used in smaller projects over a much larger area.

The major constraints in describing and mapping compositional patterns related primarily to the quality and quantity of field data and spatial data layers as opposed to analytical or logistical factors. As the quality and quantity of field and spatial data continue to develop, more detail is justified over larger regions and classifications and maps become more robust to addition of new information. Hence the greatest changes to previous classifications and maps occurred where data was most limited and where new sampling substantially improved the coverage of data (Table 7). While variation in the quality and consistency of data from disparate sources necessitated exclusion of some data (due to quality control) and degradation of some detail (e.g. re-scaling of cover-abundance estimates), field and spatial data were generally as detailed as, or better than, those available for any smaller project completed within the study area. The level of classification detail (thematic scale), resolution of mapping (spatial scale) and overall accuracy therefore did not reflect a fixed scale of interpretation, but varied as a function of the best data available (e.g. Fig. 4).

Relationships with other classifications and maps

The classification and maps produced in this study differed to varying degrees from those of previous studies that covered parts of the same region (e.g. Keith & Bedward 1999, NPWS 2002, 2003a, Tozer 2003, Gellie 2005). Consequently the descriptions and boundaries of map units may not directly correspond between studies. The degree of correspondence varies depending on a number of factors.

Some of the differences between classifications were related to edge effects. This was most evident in the Eden classification (Keith & Bedward 1999) and the south coast classification of Tindall *et al.* (2004). The amalgamation of data across the respective edges of these study areas, and inclusion of data from the gap between them, changed the context of dissimilarities between samples, resulting in some re-arrangement of the classification in that area. In contrast, the study areas of previous classifications in the Illawarra (NPWS 2002) and shale areas of the Cumberland Plain (Tozer 2003) showed little evidence of edge effects, ostensibly because the boundaries of their study areas corresponded with biogeographic zones in which the vegetation showed high contrast with that of adjacent areas.

Similar classification methods were employed across this and previous studies and were therefore unlikely to account for many differences between classifications. However, differences between some of the classifications may be partly explained by differences in their thematic scales, the levels of dissimilarity at which communities are distinguished from one another (Keith 2009). For example Keith & Bedward (1999), NPWS (2002) and NPWS (2003a) classified vegetation at a slightly finer level of detail than the current study, and therefore identified a few units that were included within more broadly defined communities in the current classification. Examples include communities 6 and 7 of Keith & Bedward (1999), which were included within a single unit (e6e7) of the current classification. Some of the additional classification detail in previous classifications derived from relatively few data and was not supported by analysis of the data over a broader spatial context. For example, seven of the units described for the Illawarra were split on the basis of three or less survey samples, while three of these units were defined almost entirely by sites excluded from the current analysis by the data screening procedures. The higher number of units recognized in the Warragamba study (NPWS 2003a) derived largely from differing interpretations of the more-or-less continuous floristic variation on sandstone (12 vs. 7 units) and Devonian sediments (12 vs. 4 units).

The coverage of data on which each classification was based also influenced differences between them and was most likely to explain the relatively low correspondence with Gellie's (2005) classification. A relatively low proportion of shared data between the two studies, and there was significant unevenness in the relative distribution of sites among land tenures which was rectified by additional sampling on private land (Table 9). Some 16 units in the present study were defined entirely by sites unavailable at the time of Gellie's (2005) survey while a further 61 units were defined by 2251 sites, of which only 229 were previously available. In addition, Gellie's (2005) classification included data from the western part of the tablelands and adjacent slopes that were beyond the scope of this study, creating differences along study boundaries.

Vegetation classifications and maps of the greater Sydney region carried out by the Royal Botanic Gardens (Keith & Benson 1988, Benson 1992, Benson & Howell 1994a, 1994b and 1994c, Fisher & Ryan 1994, Fisher *et al.* 1995) differ more markedly from those presented here than the other major surveys in the region described above. Only a small fraction of the data used here were available at the time of the greater Sydney surveys, which employed subjective methods of classification and mapping at somewhat coarser scale and resolution than the current work. Nonetheless, many of the general patterns in native vegetation related to parent material, elevation and rainfall can be discerned from the classifications and maps of both surveys and in some cases parallels can be drawn between groups of maps units. For example, map units GW p28 and p29 from this study correspond generally with map units 10 c and 10d of Benson (1992).

Evaluating uncertainties in the vegetation map

Errors and uncertainties are inherent in all maps. In the present study, the main sources of error and uncertainty were: potential biases in the content and coverage of field samples; linework and attribution derived from the interpretation of remote imagery; propagation of inaccuracies in spatial data layers used to derive the vegetation map; uncertainty in the assignment of samples to plant assemblages; and insufficient data/information to determine the merits of alternative decision rules for mapping. We evaluate each of these factors below.

Observer errors in field sampling, including variability and bias in quadrat search effort and subjective estimation of cover abundance, and species misidentifications, are difficult to quantify without replication of observers, but can be important sources of uncertainty (Baran 2001, Gorrod & Keith 2009). Together with variation in coverage, age and seasonality of samples, these errors may have an influence on classification and mapping outcomes. Stringent quality-control procedures were carried out to reduce these errors and resulted in exclusion of some 20% of available data from the analysis. Spatial and environmental bias in the distribution of samples was addressed by targeting additional sampling in environments and land tenures that were identified as sample deficient. This substantially improved the evenness and intensity of field sampling. However, some under-sampled map units would benefit from further sampling because: (i) their distributions are highly restricted or depleted (e.g. Basalt Hilltop Scrub HL p46, Wombeyan Caves Woodland DSF p219); (ii) their distributions are primarily outside the study area (e.g. Lithgow-Abercrombie Grassy Forest GW p17 and Central Coast Wet Forest WSF p599); (iii) remoteness or tenure limits access (e.g. Ettrema Gorge Forest DSF p84); or (iv) some combination of these reasons (e.g. Southern Highlands Shale Woodland WSF p268).

Observer errors also influenced image interpretation, which were compiled from 26 sources and approximately 30 different interpreters. Skill levels and interpretations of standard classification concepts used to discriminate and attribute polygons varied between interpreters to an unknown degree. Consistency also varies within interpreters due to fatigue, developing experience envelopes and other subjective factors (Burgman 2005). Automated image classification approaches offer improved consistency, but may sacrifice some discriminatory power and introduce systematic biases. Both visual and automated image interpretation are subject to errors in the imagery. These are likely to be greatest in steep and dissected terrain where shadow can limit discriminatory power and orthorectification can lead to distortion of images. Variations in colour balance and resolution also generate interpretation errors, while in fragmented landscapes boundaries between woody and non-woody vegetation may be diffuse and difficult to delineate.

To our knowledge, no Australian vegetation mapping study has yet systematically assessed observer- and image-related sources of error, but this information is crucial to inform map users about the reliability of mapped occurrences of communities and estimates of their current extent. In this study, we undertook two evaluations that were both limited to assessing the accuracy of cleared land boundaries. First, a comparison of mapped boundaries with digital imagery indicated that spatial accuracy varied from 20 (± 10) m in the Western Sydney coverage to 160 (±170) m in the CRAFTI coverage for the South Coast (Keith *et al.* 2000). Boundary accuracy in the other 24 coverages used in the compilation of the vegetation structure data layer is likely to lie within these extremes. Secondly, a comparison of mapped woody vegetation with spatially explicit field observations indicated that overall accuracy of mapped native woody vegetation (sensitivity) varied from 70% to 94% between five different aerial photograph interpretation coverages within the current study area (Keith & Simpson 2008). These estimates are likely to be higher than estimates that incorporate accuracy of mapped non-woody vegetation and different types of woody vegetation. To improve consistency, currency and resolution of mapping, we carried out new interpretation using updated imagery. Based on a subsequent comparison with digital orthophotography, boundary accuracy of the resulting mapping was estimated to be 20 (± 10) m.

Estimates of the extent of clearing in each vegetation type are sensitive to the scale and resolution of mapping. For example, the estimated area of remaining native vegetation would appear higher if mapping included smaller remnants and lower thresholds of woody cover than adopted in this study, although such an analysis would be likely to include as 'extant' a greater area of vegetation in highly modified condition. Conversely, use of coarse mapping specifications would result in smaller area estimates for extant vegetation by excluding small fragments. In both of these cases, areas mapped as Non-native Vegetation (NV) are likely to include some areas that are dominated by native vegetation. These include areas that are below the patch-size threshold for mapping and areas where native woody plants are sparse (due to clearing), but the remaining matrix of non-woody vegetation is predominantly native in species composition. These effects are most pronounced in fragmented landscapes. The estimated area of Cumberland Shale Plains Woodland, for example, approximately trebles if scattered trees with native understorey are included within the estimate (Tozer, unpublished data). Users of clearing estimates therefore need to be cognisant of the sensitivity of the estimates to variation in these parameters.

Spatial data layers varied in resolution and scale from coarse scale geology maps (1:100 000 and 1:250 000 scale) and climatic surfaces to the fine resolution digital elevation model (25 m grid cells). The scarcity of weather stations in some parts of the study area may limit the accuracy of climatic surfaces. The extensive evaluation, deconstruction and revision, which were undertaken during the development of the decision tree model, reduced the likelihood that errors in these data layers were propagated to the vegetation map. Additional field reconnaissance and floristic sampling also allowed localised errors to be identified and corrected. Several of these errors were attributed to the geology and soil landscape layers, and it is likely that further such errors will be detected in future.

Finally, map accuracy was influenced by the knowledge and field experience of the modeller, as well as the number of samples available. The influence of subjective effects is likely to be smaller in this study than 'traditional' mapping approaches in which expert input is less strongly guided by site data and interpretive protocols. The most accurately mapped communities were those with strong environmental relationships or distinctive structural features detectable on remote images, particularly if they were well represented by samples. For some communities, however, there was little information (quantitative samples or expert knowledge) on which to base choices of alternative decision rules which may produce somewhat different mapping outcomes.

Ecological Relationships and Landscape Patterns

The distribution of plant communities mapped in this study strongly reflects patterns in surface geology, climate and topography. At the local scale, differences in surface geology often correspond to relatively marked changes in both landform and soil properties (Gray & Murphy 1999), which in turn support contrasting assemblages of plant species. At regional scales, variation is more subtle, but the influence of climate is evident through the turnover of species and communities with latitude and altitude (Keith & Sanders 1990). There is also a regional distinction between communities occurring on soils derived from rocks dating to the Mesozoic Era, which dominate the Sydney Basin, compared with those on soils derived from older rocks of the Palaeozoic Era, which dominate the far south coast, escarpment and tablelands. Patterns in the distribution of native vegetation communities vary between six major landscape types which can be recognised in the Sydney – south coast and tablelands region.

1. Coastal Plains

Silty alluvial soils at low elevations on the floodplains of the Hawkesbury-Nepean, Shoalhaven, Bega and Towamba rivers and along many smaller creeks and rivers support mosaics of forested and treeless freshwater and saline wetlands (Keith 2004). Tidal zones support mangroves (SL p109) and salt marsh (SL p509). Floodplain lakes, lagoons and swamps are restricted to depressions where water tables are maintained close to the surface and are dominated by treeless wetlands (FrW p313, part FoW e60) and forested wetlands (FoW e60, p30, p44, p45, p105, p106, p107). Wet sclerophyll forests (WSF p103, p104, p110) that more typically occur on lithic substrates may sometimes be found on elevated alluvial soils, which are generally restricted to the fringes and upper reaches of large and small coastal floodplains. The Hawkesbury-Nepean floodplain supports a particularly diverse suite of forested wetlands (FoW p33, p44, p105, p106).

Marine and aeolian sand deposits are a feature of the coastline and vary in size from small beach dunes to larger sand plains such as at Seven Mile Beach, Botany Bay, Jervis Bay, Burril Lake and Disaster Bay. These sand deposits are typically dominated by shrubby dry sclerophyll forests (DSF p64), heathlands and scrubs (HL p63, e61, p139, p563). Where drainage is impeded, dry sclerophyll forests are replaced by forested wetlands (Map Units FoW p44, p45) and treeless freshwater wetlands (FrW p313).

2. Coastal Rain Shadow Valleys

Rain shadows in coastal valleys surrounded by elevated foothills are dominated by grassy woodlands (Keith 2004; Tozer in press). The study area's largest, most diverse and most northerly coastal rain shadow, the Cumberland Plain, also includes a suite of grassy dry sclerophyll forests (Keith 2004). Although sharing similar tree species, the understories of the three grassy woodland communities present on the Cumberland Plain (GW p28, p29, p514) vary in floristic composition with regional gradients in elevation and rainfall, and locally with topographic variability and soil drainage and texture. The transition from shale soils of the plain to shallower, less fertile sandy soils of the surrounding sandstone is marked by grassy dry sclerophyll forest (DSF p2) in low-rainfall areas and wet sclerophyll forests (WSF p87, p153) in wetter areas. Deposits of Tertiary alluvium produce less fertile gravelly clay loam soils than the surrounding shales and support mosaics of grassy dry sclerophyll forests (DSF p1, p4, p7, p502), while unique sclerophyll woodland and scrub communities (DSF p239, p463) occupy highly localised deposits of sand.

In the far south, the Bega and Towamba valleys support other extensive areas of coastal rain shadow grassy woodlands (GW e20p229). As on the Cumberland Plain, floristic composition varies with regional gradients in rainfall and elevation as well as topographic variability. Keith & Bedward (1999) recognised two distinct assemblages (Bega Dry Grass Forest and Candelo Dry Grass Forest) along a rainfall gradient, while other woodland and forest communities occur on more sheltered slopes and flats (GW e19) and high ridges (GW e18). Local frost hollows support species more typical of higher elevations with cool temperate climates. Smaller valleys and plains along the coast support northern (Milton – Illawarra) and southern (Batemans Bay – Towamba) variants of grassy woodlands (GW p34, e20p229), although this compositional gradient is gradual and continuous. Further inland and at higher elevation, the sandy granitoid soils of the Araluen Valley also support grassy woodlands (GW e20p229) with many species in common with the more elevated and topographically variable southern parts of the Cumberland Plain (GW p29) (Tindall *et al.* 2004).

Patches of dry rainforest are found where rainfall is somewhat higher and topography more hilly, in the Cumberland Plain margins (RF p38), the southern Illawarra around Milton (RF p40, RF p111) and near Bega (RF e1). Localised areas of scrub (HL p46) are found on exposed ridges with skeletal volcanic soils in the Illawarra.

3. Sandstone Plateaux, Scarps and Lowlands

Extensive elevated sandstone plateaux of the Sydney Basin (Woronora-Nepean Ramp, Blue Mountains, Hornsby and Morton Plateaux) are characterised by shallow, low-nutrient sandy loams and are overwhelmingly dominated by dry sclerophyll forests (Keith 2004) with diverse and abundant sclerophyllous shrubs (DSF p131, p136, p140, p142, p144, p146, p148, p149, p244, p248). Heathlands (HL p117, p120, p122, p124, p125, p126, p127) dominate exposed areas and where soils are shallow or not well drained. Upland swamps (FrW p129, p130) occur in poorly drained headwaters in high-rainfall parts of the basin. Different suites of these communities occur on the Sydney coastal plateaux, the Blue Mountains and the Morton plateau, indicating high species turnover and local endemism. Further south, sandstone substrates are rare, and occurrences around Nungatta Mountain (DSF e25, e43, e50) and Nadgee (DSF e47, HL e54, e55) support a less diverse array of related communities.

Wet sclerophyll forests and rainforests (Keith 2004) are uncommon on the sandstone plateaux, but occur on basalt flows that cap the plateau in the Blue Mountains and Southern Highlands (WSF p72, p168, p266, p268, RF p116, p516). They can also be locally dominant in high rainfall areas where the plateau is dissected to expose more fertile soils of the underlying siltstones, claystones and mudstone sin sheltered gorges or escarpment slopes. For example, the wetter parts of escarpments of the Illawarra, Blue Mountains and Morton plateau support extensive wet sclerophyll forests (WSF p95, p99, p100, p102, p110) with temperate rainforests occurring patchily in the most sheltered sites (RF p113, p114, p116, p314). The drier or more exposed escarpment slopes are dominated by dry sclerophyll forests with mixed understories of grasses and shrubs (DSF p5, p6, p88, p95, p146, p246). Fine-grained sedimentary substrates (e.g. Wandrawandian Siltstone) are also exposed on the undulating coastal lowlands between Nowra and Durras, where they support a mosaic of grassy dry and wet sclerophyll forests (DSF p85, WSF p86).

4. Southern Escarpment and Foothills

The bulk of the escarpment and foothills that run south from the Sydney Basin comprise clay loam soils derived from metasediments and acid volcanics. In less dissected, moister areas within the foothills, these soils are dominated by grassy wet sclerophyll forests (WSF p86, p90, p100, p104), while shrubby wet sclerophyll forests are common in wet gullies east of the Clyde river (Map Units WSF p99, p103). Rainforests (RF p113, e6e7) are restricted to moist protected gullies.

In the heavily dissected terrain of the upper Deua and Buckenbowra Rivers and on the southern escarpment, shrubby wet sclerophyll forests (WSF e9, e10, e11, e12, e13, e14, e15, e16, e17, p66, p103, p338) occur on sheltered slopes. These are replaced by shrubby dry sclerophyll forests (DSF e19, e27, e28, e29, e30, e31, e35, p343, e43, e44, e45, e46a, e46b, e47, e48, p89, p91, p98, p248) on exposed ridges, slopes and sites with sandier soils. Grassy wet sclerophyll forests (WSF p78, p90, p100) replace shrubby wet sclerophyll forests on soils derived from the Merimbula formation, while rainforests (RF p40, p113, p116, p317, e6e7) are scattered throughout the escarpment and foothills as many small patches within moist gullies.

5. Gorge Country

The eastern edge of the tablelands is deeply incised by sections of the Hawkesbury-Nepean, Shoalhaven, Brogo and Tuross River systems forming a complex of steep rocky gorges including the Burragorang, Coxs, Ettrema, Kanangra, Kowmung, Shoalhaven, Wollondilly, Tuross and Brogo Gorges. These deep gorges predominantly cut through metasediments and porphyries, with shallow clay-loam soils. Dry sclerophyll forests with mixed understories of grasses and shrubs (DSF e85, p5, p11, p27, p35, p36, p37, p84, p88, p202) form the dominant vegetation cover of the gorge slopes, while dry rainforests (RF p38, p40) are scattered throughout the gorges in sheltered pockets. Forested wetlands (FoW p30, p31, p32) occur within the narrow corridors of riverine alluvium.

6. Central and Southern Tablelands

The central and southern tablelands cover over one third of the study area and comprise an extensive area of rain shadow west of the escarpment range. The bulk of the tablelands comprise clay loams derived from a range of metasediments. In undulating terrain, and on flats with deeper soil development, grassy woodlands (GW p19, p22, p23, p24) are the dominant vegetation. Similar terrain on granite and basalt substrates includes a larger group of grassy woodlands (GW e24, p20, p22, p23, p24, p220, p420, p520). Grassy woodlands (GW p22, p520) also occur on well-drained areas of alluvium in broad valleys, while peaty soils accumulate in poorly drained sites that support swamp vegetation (FrW e59, p53, p55, p57, GL p257). The largest deposits of alluvium on the tablelands have accumulated on intermittent lake beds within internally draining basins. These support an ephemeral aquatic flora and periodically inundated herbfields (FrW p51).

Dry hills, ridges and dissected terrain with shallow, rocky soils support dry sclerophyll forests with shrubby understories (DSF p8, p9, p10, p14, p15). Sandy, infertile Tertiary alluvial deposits on undulating terrain between Bombay and Oallen also support shrubby dry sclerophyll forests (DSF p9, p15).

The transition between escarpment and tablelands is marked by grassy wet sclerophyll forests (WSF p268, p338). The most elevated ranges experience high rainfall (upper Blue Mountains, Gourock Range and the Southern Scarp), and are also dominated by wet sclerophyll forests (WSF p66, p70, p73, p78, p338), although shrubby dry sclerophyll forests occur on exposed ridges (DSF p8, p91, p98). Small areas of distinctive heathlands are found on exposed shallow soils on ranges on the Boyd plateau (HL p120, p121) and from the upper Shoalhaven valley south to Bombala (HL e53).

Threatening Processes

Threatening processes affecting native vegetation within the study area include habitat destruction and degradation, biological interactions with introduced plants and animals, alterations to disturbance regimes, and climate change. Each of these processes has had, and continues to have, differential effects across the range of plant communities within the study area.

Habitat destruction and degradation

The pattern of land clearing across the study area is strongly biased towards particular substrates and landscape types. Flat to undulating terrain, particularly where soils are fertile, has been preferentially cleared of native vegetation for agricultural or urban development, while shallow low-nutrient soils in strongly dissected terrain still retain large areas of native vegetation. Consequently, plant communities that typify agriculturally suitable environments have sustained proportionally large reductions in extent (Appendix 3; Fig. 5). These include virtually all 20 of the grassy woodland and grassland communities, five forested wetland communities, three freshwater wetlands and one or two types of rainforest, wet sclerophyll forest, dry sclerophyll forest and heathland. All of these occur on low-relief terrain, and most occur on comparatively rich soils.

Some of the communities that were originally fragmented by agricultural clearing are now undergoing renewed clearing pressures associated with expansion of the major urban centres of Sydney and Wollongong, as well as regional growth centres and coastal holiday settlements. Blue Gum High Forest (WSF p153), Sydney Turpentine-Ironbark Forest (WSF p87), Cumberland Shale Plains Woodland (GW p29), Eastern Suburbs Banksia Scrub (HL p563), South Coast Grassy Woodland (GW p34) and Estuarine Saltmarsh (SL p509) have been heavily fragmented by urban expansion. Outside the metropolitan areas, Estuarine Saltmarsh (SL p509), Coastal Sand Swamp Forest (FOW p55), Littoral Thicket (HL p63), South Coast Grassy Woodland (GW p34), Coastal Headland Grassland (GL p434) and Coastal Sand Forest (DSF p64) are exposed to continuing clearing associated with coastal development. Extractive industries, though restricted in area, have also resulted in some significant clearing and fragmentation, most notably affecting Agnes Banks Woodland (DSF p239), Elderslie Banksia Scrub (DSF p463) and Basalt Hilltop Scrub (HL p46).

Clearing of native vegetation has been listed as a Key Threatening Process on Schedule 3 of the NSW *Threatened Species Conservation Act* 1995. Many of the map units mentioned above are listed as Endangered Ecological Communities under that Act (Table 6), while others are yet to be assessed.

Habitat degradation is pervasive in many of the surveyed communities, results from a diversity of causes and is expressed in many different ways. The increased fragmentation that results from land clearing generates secondary processes and synergistic effects of other threatening processes, such as edge effects, degradation associated with increased human access (e.g. rubbish dumping, trampling and physical damage), weed invasion and genetic isolation. Land clearing sometimes involves selective removal of some components of the plant community, while other components persist in a modified form of the original community. For example, many of the native grasslands mapped by Walter & Schelling (2004) on the southern tablelands and by Pellow and French (2003) at the Orchard Hills Defence Site (western Sydney) were originally grassy woodlands, from which the woody components of the native vegetation had been removed. Although these non-woody remnants are traditionally lumped with 'cleared land', they often have significant conservation values because they retain components of the biota complementary to those represented within woody remnants (Keith *et al.* 2005).

Other forms of habitat degradation involve modification to soils. Soils in some areas have undergone nutrient enrichment, either directly as a result of fertiliser application (particularly superphosphate and nitrogen-based fertilisers) or indirectly as a result of enriched stormwater runoff from improved pastures, croplands, urban or industrial areas upslope (e.g. Clements 1983, King & Buckney 2002, Leishman *et al.* 2004). The most extensively affected communities include grassy woodlands, grasslands and wetlands. Wetlands and riparian vegetation are particularly vulnerable because, despite some resilience to nutrient enrichment, they act as sinks in the landscape where large quantities of nutrients accumulate and transform habitats to a degree that they become unsuitable for many native species. Although the exposure of dry sclerophyll forests and heathlands to nutrient enrichment is more localised, the impacts on these communities are generally more severe because many of their component species have adaptations to extract nutrients from highly infertile soils that make them highly sensitive to toxicity from elevated levels of nutrients, particularly phosphorus, or to competition from faster-growing exotic species. Soils have also undergone compaction and/or erosion, particularly where the cover of native vegetation has been partially or completely removed and/or where stocking rates have been high (Beadle 1948). This reduces the ability to recruit seedlings in many native plant species and may also reduce survival rates of existing plants.

Biological interactions

The invasion and spread of introduced plants is the most serious biological interaction that threatens native vegetation in the region. Introduced plants may displace native plant taxa and 'transform' the habitats of native plants and animals (Richardson *et al.* 2000, Grice *et al.* 2004). Transformer weeds may alter vegetation structure, reduce available light, nutrients and water available to native plants, reduce shelter, food or breeding resources available to native animals or alter fire regimes, for example, by reducing the flammability of vegetation. Disturbances resulting from urban or rural development and agriculture (e.g. removal or reduction of native vegetation cover, nutrient enrichment of soils, changes to hydrology, physical disturbance to soil) may enhance growth, reproduction and dispersal of introduced plants, giving them competitive dominance over native species.

Riparian zones and fragmented remnant vegetation with long edges are highly susceptible to weed invasion. Within the study area, the communities most prone to weed invasion include grasslands (GL p257, p434), grassy woodlands (GW e18, e20p229, e24, p2, p3, p20, p22–24, p28, p29, p34, p220, p420, p520), wet sclerophyll forests with grassy understories (WSF e15, p87, p143, p168, p266, p268), forested wetlands (FOW e17, e38, e39, e60, m15, p30, p32, p44, p45, p105–107) and swamp meadows (FrW e56, e57, e59, p51, p55, p57).

Exotic plant species represented approximately 19% of the total flora recorded in the survey and about 25% of the total known exotic flora in New South Wales. This may slightly under-estimate the extent of invasions because the most degraded forms of native vegetation and non-native vegetation were poorly represented among samples. The exotic species recorded fall into four main groups: perennial grasses, vines, shrubs and forbs. Many species from these groups are listed as Key Threatening Processes under the NSW *Threatened Species Conservation Act* 1995 (NSW Scientific Committee, undated). The most frequently recorded perennial grasses include *Chloris gayana, Ehrharta erecta, Eragrostis curvula, Nassella trichotoma, Paspalum dilatatum, Pennisetum clandestinum, Phalaris aquatica* and *Setaria gracilis*. These species readily invade disturbed grassy woodlands, grasslands, forested wetlands and swamp meadows, as well as grassy wet and dry sclerophyll forests. Introduced vines (e.g. *Anredera cordifolia, Araujia sericifera, Asparagus* spp., *Cardiospermum grandiflorum, Ipomoea* spp., *Lonicera japonica*) are especially problematic in disturbed wet sclerophyll forests and rainforests. Shrubs such as *Ageratina adenophora, Lantana camara, Ligustrum* spp., *Ochna serrulata, Olea europaea* subsp. *cuspidata* and *Rubus* spp. readily invade mesic habitats (RF p111, p112, p210, WSF p87, p143, p168, p266, HL p63). Several of these species have fleshy fruits that are dispersed by native birds and appear capable of invading some habitats that have apparently undergone little recent disturbance. For example, African

Olive has undergone a conspicuous expansion into grassy woodlands and wet sclerophyll forests in recent decades (Cuneo & Leishman 2007) and was recorded within 43% of the 198 samples within map units GW p28 and GW p29, which represent Critically Endangered Cumberland Plain Woodland. Other shrub species threaten more specialised habitats, including *Salix* spp. (forested and freshwater wetlands) and *Chrysanthemoides monilifera* (communities on coastal sand plains including DSF p64, HL e61, p63, p139, p563, RF p210). Herbaceous species are pervasive throughout many grassy woodlands, grasslands, forested and freshwater wetlands and grassy wet and dry sclerophyll forests. Although this group includes the most frequently recorded exotic taxa in the region (*Hypochaeris radicata*, *Cirsium vulgare*, *Senecio madagascariensis* and *Plantago lanceolata*), their impacts on native plant communities tend to be less severe, as they transform habitats less aggressively than some species in the other weed groups. The exceptions are aquatic forbs such as *Eichhornia crassipes, Ludwigia* spp. and *Salvinia molesta, which* pose significant threats to freshwater and forested wetlands (FrW p313, FoW p32, p33, p105).

Excessive grazing and browsing by feral and domestic vertebrate herbivores is a second group of biological interactions that pose threats to native vegetation in the region. Grazing and browsing may result in significant changes in the species diversity and structural complexity of native vegetation, depending on the grazing regimes and resilience of component plant taxa (Leigh & Holgate 1979, Wimbush & Costin 1979, Prober & Thiele 1995, Clarke 2000). The resilience of individual plant taxa to grazing depends on their palatability, regenerative capacity, growth form and the existence and phenology of dormant life stages relative to the grazing regimes that they are exposed to (Clarke 2000). Continued heavy grazing may reduce the relative abundance or eliminate a number of woody taxa and palatable forbs and simplify the structure of native vegetation. The simplification of vegetation structure has implications for the suitability of habitats for a wide range of native fauna.

The vegetation most susceptible to grazing impacts includes remnants of grasslands, grassy woodlands, wetlands and grassy wet and dry sclerophyll forests. The most affected communities occur within the pastoral districts of the Central and Southern Tablelands and Southern Highlands (GW e24, p17, p20, p22–24, p220, p420, p520; GL p257, p434; FrW p51, p53, p55, p57, p257, FOW p54, DSF p8–10, p14, WSF p73, p168, p266, p268) and coastal rainshadow valleys (GW e20p229, p2, p3, p28, p29, DSF p1, p502). The principal herbivores that affect native vegetation in the region include feral goats, rabbits, deer, pigs, and domestic sheep and cattle. All of these feral herbivores are listed as Key Threatening Processes under the NSW *Threatened Species Conservation Act* 1995 (NSW Scientific Committee, undated). Their effects, and those of domestic herbivores, may add to those of native macropods, which may have significant impacts in localised areas where their densities are artificially inflated.

Excessive grazing and browsing may interact with other threatening processes producing synergistic impacts on native vegetation. For example, heavy grazing may initiate or accelerate erosion of topsoil. These effects are exacerbated where soils are unconsolidated, on inclined slopes or low in clay content, particularly where hoofed animals are involved. Grazing may also provide gaps for the establishment of introduced plants, which may also compete with some native plant taxa resulting in further declines in native species diversity and alterations to vegetation structure. Flushes of weed invasion commonly occur after long periods of grazing have opened up the structure of native vegetation, allowing entry and establishment of weeds when grazing activity is temporarily or permanently reduced. Active management is required to control weeds during such periods until cover of native vegetation has re-established, providing greater resilience to invasion. The effects of grazing may also interact with climatic variability, particularly where remnants of native vegetation are managed as stored fodder and grazed more heavily during drought years

Alteration to disturbance regimes

Alteration to two key disturbance regimes (water and fire) poses threats to numerous plant communities within the region. Hydrological changes, including the draining of wetlands (e.g. Wollogorang Lagoon, Nowra Floodplain), increases in stormwater runoff from sealed surfaces (e.g. Lane Cove and Georges River catchments), impoundment of water in reservoirs and dams, and interruption to stream and seepage flows (e.g. metropolitan catchments) affect the vegetation of freshwater and saline wetlands and riparian corridors (Map Units FOW e17, e38, e39, e60, m15, p30–33, p44, p45, p54, p58, p105–107, SL p109, p509, FrW e56, e57, e59, p51, p53, p56, p55, p57, p257, p313). Significant areas of wetland have been drained in the past for agricultural and pastoral development (e.g. around Nowra, Windsor, Jamberoo, Albion Park, Breadalbane, Goulburn and Taralga), while more localised infilling and reclamation of wetlands continues for urban, industrial or recreational development in the Sydney – Illawarra metropolitan area and around expanding settlements on the south coast. Alteration to the natural flow regimes of rivers, streams, floodplains and wetlands is listed as a Key Threatening Process on Schedule 3 of the NSW *Threatened Species Conservation Act* 1995.

Changes in fire regimes may result in declines of some plant species, enhanced spread of some others, and changes to vegetation structure. This occurs through a range of different mechanisms (Keith 1996). Fauna may be affected by resulting changes in the availability of food, shelter and breeding sites (Whelan *et al.* 2002). Some urban bushland areas are exposed to increased ignition rates due to arson and hazard reduction management, while in some rural areas, fire is used by some graziers to promote green pick for livestock. Under these circumstances native vegetation may be exposed to high fire frequencies that result in declines of many woody plant species, the spread of native rhizomatous plants and some introduced species. Ecological consequences of high frequency fire are listed as a Key Threatening Process on Schedule 3 of the NSW *Threatened Species Conservation Act* (1995). In other areas, there may be substantial declines in fire frequencies which may be associated with isolation and fire exclusion from vegetation remnants or long-term changes in fuel structure attributable to processes such as nutrient enrichment or grazing. Fire exclusion may result in the loss of species that depend on fires as a cue to recruitment, including relatively short-lived native plants and those without persistent seed banks or other types of propagules.

Climate change

Climate change is the most pervasive and least predictable of all threatening processes. The communities likely to be most affected include those that are restricted to cool temperate bioclimatic zones (e.g. RF p317, WSF e9, e10, e11, p338), those susceptible to climatic drying or reduced rainfall reliability (e.g. FrW p51, p55, p130, FoW p32, p54) and those likely to contract as a result of sea-level rise (e.g. DSF p64, FoW e60, p45, p104, FrW p313, SL509). Major impacts of climate change are likely to be played out through interactions with other threatening processes, including habitat loss and degradation, invasion of exotic species and changes to hydrological and fire regimes. Anticipatory and adaptive management of these other threats and their synergies are therefore an essential component of any strategy for climate change adaptation (Dunlop & Brown 2008, Auld & Keith 2009).

Conservation

Approximately 66% of the study area still has native vegetation cover, comprising 27% within dedicated conservation reserves, 20% on freehold land, 13% within State Forests and 5% on other crown lands (see Table 5 above). These tenures are of course not distributed evenly across the landscape; historical allocation of lands to maximise human use has meant that freehold lands (comprising 51% of the total study area) dominate the more fertile and undulating tablelands and coastal river valleys, while State Forests (15% of study area) and conservation reserves (28%) are concentrated along the rugged coastal escarpments and ranges. These patterns are reflected in the clearing and reservation status of different vegetation types.

Some 115 map units are estimated to have 70% or more of their original extent remaining uncleared (see Table 8 above), dominated by heaths, rainforests and dry and wet sclerophyll forests of steep terrain and/or poor soils (shallow, rocky or sandy, low fertility). The majority of these less-cleared units are well represented in conservation reserves, with 57 units having more than 50% of their original extent reserved in National Parks, Nature Reserves or Flora Reserves. However, 25 units have less than 30% of original extent reserved and their extant areas occur predominantly on other tenures including State Forests, water catchment lands, freehold and coastal crown land, where they may be subject to continuing threats such as frequent fire or logging.

Conversely, some 38 units have been heavily cleared, with an estimated loss of 70% or more of original extent (Table 8), and these units are dominated by swamps, grasslands, woodlands, and basalt and alluvial forests. Almost all of these over-cleared units are also poorly conserved, with 35 units estimated to have less than 10% of their original extent within conservation reserves. Extant areas of these units are predominantly on freehold lands, and commonly occur as small scattered remnants subject to ongoing degradation including over-grazing, weed invasion and altered fire or flooding regimes.

A number of communities are of conservation concern because their distributions are naturally restricted. Restricted distributions predispose communities and species to greater impacts from stochastic events from known threats, such as those outlined above, as well as unexpected threats. The most spatially restricted map units in the study area are typically limited to rare substrates and landforms (Map Units RF e1, p314, p317, WSF p72, p68, DSF p219, p239, p463, HL e52, m83, p46, p120, p121, p126), localised areas of poor drainage (DSF p4, FoW p44, p54, m15, FrW p56, p129, p303), and specialised coastal habitats (RF p210, HL p127, GL p434, SL p509). Other spatially restricted units are apparently at the limit of their distribution in the study area and have more extensive distributions elsewhere (e.g. WSF p599, GW p17). Seven of the restricted units are distributed almost entirely within conservation or water catchment reserves (Map Units HL e52, HL p120, HL p121, HL p126, FrW p303, WSF p68), or partly within reserves (HL m83), while three have little or no representation in any conservation reserves (Map Units HL p46, FoW m15 and FrW p56) (Appendix 3).

The study area contains a large number of listed Threatened Ecological Communities (see Table 6 above), partly reflecting the diversity of the region and the levels and diversity of threatening processes that influence its native vegetation. Many of the heavily cleared, poorly conserved and/or spatially restricted map units discussed above are referrable to ecological communities recognised as threatened at state or national level, and these units must be targeted as priorities for coordinated incentive, education and regulatory programs including protection from further clearing, voluntary conservation agreements with private landholders, and education and incentive programs for the management of threatening processes.

Acknowledgements

This project was initially funded by the NSW Government under the NSW Native Vegetation Mapping Program (managed by the former NSW Department of Land and

Water Conservation (DLWC)). The efforts and assistance of the Program manager, Bob Denholm, are gratefully acknowledged. We thank staff from the former Department of Infrastructure Planning and Natural Resources (DIPNR) Dominic Sivertsen, Ross Peacock, Tim Hudspith, Hugh Jones, Terry Koen, Fred DeClosey, Peter Smith, Merrin Tozer for advice, training, technical assistance and assistance with project direction and management. Grant Bywater (former Department of Natural Resources) facilitated the revision and extension of the project to support the south coast regional planning strategies. We gratefully acknowledge the contributions of Simon Hunter, Peta Williams and Karen Cranney for cartographic assistance, data management, air photo interpretation and field assistance. We also thank former Department of Environment and Conservation staff in Southern and Central Directorates for their assistance and contributions. This includes Daniel Connolly, Nathan Kearnes, Peter Ewin, Julie Ravallion, Phil Craven, Les Mitchell, Rainer Rehwinkle, Tom Barrett, Keith McDougall, Ian Jackett, Max Beukers and Lyndsay Holme. Special thanks to Shawn Capararo for assistance and management of air photos and associated data. Field survey preparation and data collection was assisted by many including Mulwaree, Evans and Wingecarribee Councils, Steve House, Steve Bell, Jackie Miles, Roger Lembit, Lisa Holman, Merrin Tozer, Greg Tozer, Simon Williams, Vanessa Allen, Gilly Young, James Crooks, John Reynolds, Rob Adam, Lyall Bogie, Paul O'Keefe, Jacqueline Holland, Cath Richardson, Jo Lesak, Philip Gleeson, Nick Corkish, Jedda Lemmon, and Nathan Kearnes We apologise to other enthusiastic volunteers who have inadvertently been overlooked. GIS support and advice was provided by Chris Togher, Ed Knowles and Martin Mutendeudzi. Air photo interpretation was carried out by Owen Maguire and Bob Wilson. Thanks to Simon Ferrier, Glenn Manion and Michael Drielsma for assistance with the Gap Analysis Tool and DEM manipulation. We gratefully acknowledge the map unit photographs provided by others including Daniel Connolly, Nathan Kearnes, Jedda Lemon, Nick Corkish, Jackie Miles, Mike Cufer and James Crooks. This project has built on numerous earlier studies and we gratefully acknowledge the generous contributions of data made by many individuals and organisations listed in Appendices 4 and 5. We gratefully acknowledge the patience, time and efforts of Barbara Wiecek, Peter Hind and all staff involved with the Botanical Information Service at the RBG, Sydney. Special thanks to Michael Bedward, who produced software, scripts, advice and assistance in support of the project. Finally, we thank all of the landholders who generously permitted access to their properties. This project benefited greatly through their co-operation, interest and involvement.

References

Andrew, D. (2001) *Post-fire vertebrate fauna survey, Royal and Heathcote National Parks and Garrawarra State Recreation Area*. NSW National Parks and Wildlife Service, Hurstville.

Ashton, D.H. (1981) Fire in tall open forests (wet sclerophyll forests) Pp. 339–368 in A.M. Gill, R.H. Groves & I.R. Noble (eds) *Fire and the Australian Biota*. Australian Academy of Science, Canberra.

Ashton, D.H. & Frankenberg, J. (1976) Ecological studies of *Acmena smithii* (Poir.) Merrill and Perry with special reference to Wilsons Promontory. *Australian Journal of Botany* 24: 453–487.

Auld, T. D. & Keith, D. A. (2009) Dealing with threats: Integrating science and management. *Ecological Management and Restoration* 10.

Austin, M.P. (1978) Vegetation. Pp. 44–67 in M.P. Austin & K.D. Cocks (eds) *Land use on the south coast of NSW*. CSIRO, Canberra.

Australian Bureau of Statistics (2004) Census Data 2001. Commonwealth of Australia, Canberra. www.abs.gov.au

Banks J.C.G. (1990) *The fire history for two forest types in Glenbog State Forest, N.S.W.* Report to the Joint Scientific Committee on the South East Forests, Canberra.

Bannerman, S.M & Hazelton, P.A. (1990) *Soil Landscapes of the Penrith 1:100 000 Sheet*. Soil Conservation Service of NSW, Sydney.

Baran, N. (2001) *Effective survey methods for detecting plants*. MSc thesis. University of Melbourne.

Barnes, R., Watkins, J., Troedson, A., Hashimoto, R., Cain, L., Malloch, K., Jaworska, J., McEvilly, R. & Brownlow, J. (2005) *NSW Coastal Quaternary Geology Data Package*. Comprehensive Coastal Assessment Project CCA-1 Geology Integration and Upgrade. NSW Department of Primary Industries.

Beadle,N.C.W. (1948) The Vegetation and Pastures of Western New South Wales with Special Reference to Soil Erosion. NSW Government Printer, Sydney.

Bedward, M., Keith, D.A. and Pressey, R.L. (1992) Homogeneity analysis: assessing the utility of classifications and maps of natural resources. *Australian Journal of Ecology* 17: 133–139.

Belbin, L. (1987) The use of non-hierarchical allocation methods for clustering large sets of data. *Australian Computer Journal* 19: 32–41.

Belbin, L. (1994) *PATN. Pattern Analysis Package*. CSIRO, Canberra.

Bell, S. (1996) Unpublished floristic survey sites, Mount Piper Power Station.

Bell, S. and Douglas, S. (2002) *Clyde River National Park Vegetation Survey*. Report to NSW National Parks and Wildlife Service.

Benson, D.H. (1981) The vegetation of the Agnes Banks sand deposit, Richmond, New South Wales. *Cunninghamia* 1(1): 35–57.

Benson, D.H. (1992.) The natural vegetation of the Penrith 1:100 000 map sheet. *Cunninghamia* 2(4): 541–596.

Benson, D.H. and Howell, J. (1990) *Taken for granted: the bushland of Sydney and its suburbs*. Kangaroo Press, Sydney.

Benson, D.H. and Howell, J. (1994a) *Hawkesbury-Nepean Catchment Vegetation Mapping: Explanatory Notes for the Wollongong 1:100 000 Map Sheet*. Ecology Section, National Herbarium, Royal Botanic Gardens, Sydney.

Benson, D.H. & Howell, J. (1994b) The natural vegetation of the Sydney 1:100 000 map sheet. *Cunninghamia* 3(4): 677–1004.

Benson, D. and Howell, J. (1994c) *Hawkesbury-Nepean Catchment Vegetation Mapping: Explanatory Notes for the Moss Vale – Kiama 1:100 000 Vegetation Map Sheets*. Draft Report as part of the Hawkesbury-Nepean Catchment Vegetation Mapping Studies for Sydney Water. National Herbarium of New South Wales, Royal Botanic Gardens, Sydney.

Benson, J.S. (1994) The native grasslands of the Monaro region: southern tablelands of New South Wales. *Cunninghamia* 3: 609–650.

Benson, J.S. & Ashby.E.M. (2000) The natural vegetation of the Guyra 1:100 000 map sheet, New England Bioregion of New South Wales. *Cunninghamia* 6, 747–872

Benson, J.S. & Jacobs,S.W.L. (1994) Plant communities of the Monaro lakes. *Cunninghamia* 3: 651–676.

Best, J.G., D'Addario,G.W., Walpole,B.P. & Rose,G. (1963) *Canberra 1:250 000 Geological Sheet SI/55–16*. 1st Edition. Geological Survey of New South Wales, Sydney.

Beukers, M. (undated-a) Unpublished vegetation survey data, Ecologically Sustainable Forest Management program. NPWS Far South Coast Region. NSW NPWS, Eden.

Beukers, M. (undated-b) Unpublished vegetation survey data, Voluntary Conservation Area survey program. NPWS Far South Coast Region. NSW NPWS, Eden.

Beukers, M. (undated-c) Unpublished vegetation survey data, Eden CRA Map Validation. NPWS Far South Coast Region. NSW NPWS, Eden.

Black, D. (2000a) Unpublished vegetation plot data, Budderoo National Park. NSW National Parks and Wildlife Service.

Black, D. (2000b) Unpublished vegetation plot data, Morton NP: Bugong Area, Burma FT Burning Block. NSW National Parks and Wildlife Service.

Branagan, D.F. & Packham, G.H. (2000) *Field Geology of New South Wales*. 3rd Edition. NSW Department of Mineral Resources, Sydney.

Bridges, R.G. (1983) Integrated logging and regeneration in the silvertop ash-stringybark forests of the Eden region. *Research Paper No. 2*. Forestry Commission of N.S.W, Sydney.

Brunker, R.L. & Offenberg, A.C. (1970) *Goulburn 1: 250 000 Geological Sheet SI/55–12*. 1st Edition. Geological Survey of New South Wales, Sydney.

Bryan, J.H. (1966) *Sydney 1:250 000 Geological Sheet SI/56–05*. 3rd Edition. Geological Survey of New South Wales, Sydney.

Burgman,M. (2005) *Risks and Decisions for Conservation and Environmental Management*. Cambridge University Press, Cambridge.

Chapman,G.A. & Murphy, C.L. (1989) *Soil Landscapes of the Sydney 1:100 000 Sheet*. Soil Conservation Service of NSW, Sydney.

Clark,N.R. & Jones,D.C. (1991) *Penrith 1:100 000 Geological Series Sheet 9030*. 1st edition. Geological Survey of New South Wales, Sydney.

Clarke, P. J. (2000) Plant population processes in temperate woodlands in eastern Australia – premises for management. Pp 248–270 in Hobbs,R.J. & Yates,C.J.(eds) *Temperate eucalypt woodlands in Australia: biology, conservation, management and restoration*. Surrey Beatty & Sons, Chipping Norton.

Clarke, P. J., Copeland, L. M., Noble, N. E., Bale, C. L. and Williams, J. B. (2000) *The vegetation and plant species of New England National Park*. University of New England, Armidale.

Clayton-Greene, K.A. & Wimbush, D.J. (1988) Acacia dry scrub communities in the Byadbo area of the Snowy Mountains. *Cunninghamia* 2: 9–24.

Clements, A. (1983) Suburban development and resultant changes in the vegetation of the bushland of the northern Sydney region. *Australian Journal of Ecology* **8,** 307–319.

Clements, A., Rodd, T., Rodd, J. and Moore, R. (2000) *Shale/Sandstone Transition Forest within the Blue Mountains local government area*. Anne Marie Clements & Associates, unpublished report to Blue Mountains City Council.

Commonwealth Bureau of Meteorology (2004) Climate Statistics for Australian Sites – New South Wales & ACT. www.bom.gov.au

Commonwealth of Australia (1992) *National Forest Policy Statement. A New Focus for Australian Forests*. Second edition. Australian Government Publishing Service, Canberra.

Costin, A.B. (1954) *A study of the ecosystems of the Monaro region of New South Wales*. Soil Conservation Service of New South Wales, Sydney.

CSIRO (1996) *Pre 1750 vegetation mapping for the south coast forests area*. CSIRO Division of Wildlife and Ecology, Canberra.

CSIRO (1999a) Unpublished survey data: Clyde Mountain and environs. CSIRO, Canberra.

CSIRO (1999b) Unpublished survey data: Kosciuszko survey sites. CSIRO, Canberra.

Cuneo,P. & Leishman,M.R. (2006) African Olive (Olea europaea subsp cuspidata) as an environmental weed in eastern Australia: a review. *Cunninghamia* 9, 545–57.

Douglas, S. (2001) Native vegetation mapping of Areas 1 to 5 in Blue Mountains City local government area. A report prepared for Blue Mountains City Council.

Douglas, S. and Bell, S. (2002) *Bimberamala National Park Vegetation Survey*. NSW National Parks and Wildlife Service.

Dunlop,M. & Brown,P. (2008) *Implications of climate change for Australia's National Reserve System: a preliminary assessment*. CSIRO, Canberra.

EcoLogical Australia Pty Ltd (2002) *Wingecarribee Biodiversity Study: Vegetation mapping, threatened species, corridors and conservation assessment*. Report prepared for Wingecarribee Shire Council.

ESP (2001) Native vegetation mapping of Areas 1 to 5 in Blue Mountains City local government area. Report to BMCC by Ecological Surveys & Planning Pty Ltd, Hornsby.

Faith, D.P. (1991) Effective pattern analysis methods for nature conservation. pp. 47–53 in Margules, C.R. & Austin, M.P. (eds) *Nature Conservation: Cost Effective Surveys and Data Analysis*. CSIRO, Australia.

Faith, D.P. & Walker, P.A. (1996) Environmental diversity: on the best-possible use of surrogate data for assessing the relative biodiversity of sets of areas. *Biodiversity and Conservation* 5: 399–415.

Felton, E.A. (1974) *Goulburn 1:250 000 Metallogenic Map Sheet SI 55–12*. 1st Edition (reprinted). Geological Survey of New South Wales, Sydney.

Felton, E.A. & Huleatt, M.B. (1975) *Braidwood 1:100 000 Geological Sheet 8827*. 1st Edition. Geological Survey of New South Wales, Sydney.

Ferrier, S. (2002) Mapping spatial pattern in biodiversity for regional conservation planning: where to from here? *Systematic Biology* 51: 331–363.

Fisher, M. and Ryan, K. (1994) Hawkesbury-Nepean Catchment Vegetation Mapping: Explanatory Notes for the Taralga and Oberon 1:100 000 Map Sheets. Ecology Section, National Herbarium, Royal Botanic Gardens Sydney.

Fisher, M., Ryan, K. & Lembit, R. (1995) The natural vegetation of the Burragorang 1:100 000 map sheet. *Cunninghamia* 4(2): 143–215.

Floyd, A.G. (1990) *Australian Rainforests in New South Wales. Volume 2*. Surrey Beatty and Sons, Chipping Norton.

Forbes, S.J., Walsh, N.J. & Gullan, P.K. (1982) Vegetation of East Gippsland. *Muelleria* 5: 53–113

French, K., Pellow, B. and Henderson, M. (2000) Vegetation of the Holsworthy Military Area. *Cunninghamia* 6(4): 893–940.

Gellie, N. (2002) *Vegetation, Rare Plants and Weed Mapping, Monga National Park*. Unpublished report to NSW National Parks And Wildlife Service. EcoGIS Consultant.

Gellie, N.J.H. (2005) Native Vegetation of the Southern Forests: Southeast Highlands, Australian Alps, South-west Slopes, and SE Corner bioregions. *Cunninghamia* 9(2): 219–254.

Gellie, N. (undated) Unpublished miscellaneous floristic survey sites, Blue Mountains area. NSW National Parks and Wildlife Service.

Gilligan, L.B. (1974) *Canberra 1:250 000 Metallogenic Map Sheet SI 55–16*. 1st Edition (reprinted) Geological Survey of New South Wales, Sydney.

Gilmour, P.M. (1985) *Vegetation Survey of Deua National Park*. Unpublished report to NSW National Parks and Wildlife Service, Narooma District.

Gorrod, E. & Keith, D. A. (2009) Observer variation in field assessments of vegetation condition: Implications for biodiversity conservation. *Ecological Management and Restoration* 10, in press.

Gray,J.M. & Murphy,B.W. (1999) *Parent Material and Soils. A Guide to the Influence of Parent Material on Soil Distribution in Eastern Australia*. Technical Report No. 45.NSW Department of Land & Water Conservation, Parramatta.

Grice, A. C., Field, A. R. and McFadyen, R. E. C. (2004) Quantifying the effects of weeds on biodiversity: Beyond Blind Freddy's test. Pp. 464–468 in Sindel,B.M. & Johnson,S.B. (eds) *Proceedings of the 14th Australian Weeds Conference*. Weed Society of New South Wales, Wagga Wagga.

Groves R. H., Keraitis K. and Moore C. W. E. (1973) Relative growth of *Themeda australis and Poa labillardieri* in pots in response to phosphorus and nitrogen. *Australian Journal of Botany* **21**, 1–11.

Harden, G.J.(ed) (1990, 1991, 1992, 1993 & 2002) *Flora of New South Wales* Volumes 1–4. University of NSW Press, Kensington.

Hazelton, P.A. (1990) *Soil Landscapes of the Wollongong-Port Hacking 1:100 000 sheet*. Soil Conservation Service of NSW, Sydney.

Hazelton, P.A. (1992) *Soil Landscapes of the Kiama 1:100 000 sheet*. Soil Conservation Service of NSW, Sydney.

Helman,C.E. (1983) *Inventory Analysis of Southern NSW Rainforest Vegetation*. MSc Thesis, University of New England, Armidale.

Hibberd, J. and Taws, N. (1993) *The Long Paddock Revisited 15 Years On: A Comparative Study of the Condition and Use of Travelling Stock Reserves in the Southern Tablelands 1977–1993*. Unpublished Report for the Nature Conservation CouncilHouse, S. (2003) *Lower Hunter and Central Coast Regional Biodiversity Conservation Strategy, Technical Report, Digital aerial photo interpretation and updated extant vegetation community map*. Lower Hunter and Central Coast Regional Environmental Management Strategy, Callaghan, NSW.

House, S. (2003) *Vegetation survey of Wingecarribee Shire*. Unpublished report to Wingecarribee Shire Council.

Hunter,J.T. & Sheringham,P. (2008) Vegetation and floristic diversity in Gibraltar Range and part of Washpool National Parks, New South Wales. *Cunninghamia* 10(3): 439–474.

Hutchinson, M.F. (1989) *A new objective method for spatial interpolation of meteorological variables from irregular networks applied to the estimation of monthly mean solar radiation, temperature, precipitation and wind-run*. Technical Memorandum 89/5, CSIRO Division of Water Resources, Canberra.

Ismay, K., Lewer, S., DeLuca, S. MacKenzie-Kay, M., Powrie, S.,Burns, M., Ryan, S. and Chaffey, D. (2004) *Native vegetation report. Cobbora, Coolah, Coonabarabran, Mendooran and Tambar Springs 1:100 000 map sheets*. Draft report, New South Wales Department of Natural Resources, Parramatta.

James, T., Lembit, R., Burcher, P. and Ecograph Consulting (in prep.Nov 2002) *Natural Asset Mapping for Baulkham Hills Shire Council – Plant Communities in Baulkham Hills Shire*. Report commissioned by BHSC.

Jenkins, B.R. (1996) *Soil Landscapes of the Braidwood 1:100 000 sheet*. Soil Conservation Service of NSW, Sydney.

Jurskis, V., Shields, R. and Binns, D. (1995) Flora Survey, Queanbeyan/Badja Environmental Impact Statement Area, Southern Region, New South Wales. Supporting Document 3, Environmental Impact Statement for Queanbeyan & Badja Management Areas. Research Division, State Forests of NSW, Beecroft.

Keith, D.A. (1990) Rare and biogeographically significant vascular plant species of the Eden region, south-eastern NSW: a listing for the 'fine-filter' approach. *Proceedings of the Linnean Society of New South Wales* 112: 111–132.

Keith, D.A. (1994) Floristics, structure and diversity of natural vegetation in the O'Hares Creek catchment, south of Sydney. *Cunninghamia* 3(3): 543–594.

Keith, D.A. (1995) Involving ecologists and local communities in survey, planning and action for conservation in a rural landscape: an example from the Bega Valley, New South Wales. In Saunders,D.A. Craig,J.L. & Mittiske,E. (eds) *Nature Conservation 4: The role of networks*. Surrey Beatty and Sons, Chipping Norton.

Keith, D.A. (1996) Fire-driven extinction of plant populations: a synthesis of theory and review of evidence from Australian vegetation. *Proceedings of the Linnean Society of New South Wales* **116**, 37–78.

Keith, D.A. (2002) *A compilation map of native vegetation for New South Wales*. Unpublished report. NSW National Parks and Wildlife Service.

Keith, D. (2004) *Ocean Shores to Desert Dunes: The native vegetation of NSW and the ACT*. NSW Department of Environment and Conservation, Hurstville.

Keith, D.A. (2009) The interpretation, assessment and conservation of ecological communities. *Ecological Management and Restoration* 10, in press.

Keith, D.A. & Ashby, E. (1992) Vascular plants of conservation significance in the South East Forests of New South Wales. *Occasional Paper* 11. NSW National Parks and Wildlife Service, Hurstville.

Keith, D.A. & Bedward, M. (1999) Native vegetation of the South East Forests region, Eden, New South Wales. *Cunninghamia* 6(1): 1–218.

Keith, D.A. & Benson, D.H. (1988) The natural vegetation of the Katoomba 1:100,000 map sheet. *Cunninghamia* 2(1): 107–144.

Keith,D.A., Miles,J. & Mackenzie,B.D.E. (1999) Vascular flora of the South East Forests region, Eden, New South Wales. Cunninghamia 6(1): 219–281.

Keith D, Pellow B, & Tozer M (2005) Can't see the biodiversity for the trees? Implications of alternative landscape models for conservation of Cumberland Plain Woodlands. P6 in Pellow,B., Morris,C., Bedward,M., Hill,S., Sanders,J. & Clark,J. (eds.) *The ecology and management of Cumberland Plain habitats: a symposium*. University of Western Sydney, Campbelltown.

Keith,D.A. & Sanders,J.M. (1990) Vegetation of the Eden region, south-eastern Australia: species composition, diversity and structure. *Journal of Vegetation Science* 1: 203–232.

Keith, D. A. & Simpson, C. C. (2008) A protocol for assessment and integration of vegetation maps, with an application to spatial data sets from south-eastern Australia. *Austral Ecology* 33, 761–774.

Keith, D.A., Simpson, C., Tozer, M.G. and Rodoreda, S. (2007) Contemporary and Historical Descriptions of the Vegetation of Brundee and Saltwater Swamps on the Lower Shoalhaven River Floodplain, Southeastern Australia. *Proceedings of the Linnean Society of NSW*, Vol. 128, pp 123–153.

Keith, D. A. and Tozer, M. G. (1998) Vegetation of Royal National Park and surrounds. Unpublished data. NSW National Parks and Wildlife Service, Hurstville.

Keith, D., Tozer, M. and Hunter, S. (2000) An evaluation of vegetation mapping for the Priority 5 Mapping Area (based on the Greater Illawarra/Southern Highlands native vegetation region). NSW National Parks and Wildlife Service. Unpublished report.

Kendall, P., Maguire, O. and Kowel, C. (2003) Wadbilliga National Park and Bemboka and Glenbog Sections of the South East Forest National Park. API Vegetation Mapping. Unpublished report to NSW National Parks And Wildlife Service.

Kendall, P. (2005) API vegetation mapping. Unpublished report to NSW National Parks & Wildlife Service.

King, D.P. (1994) Soil Landscapes of the Katoomba 1:100 000 Sheet. Soil Conservation Service of NSW, Sydney.

King,S.A. & Buckney,R.T. (2002) Invasion of exotic plants in nutrient-enriched urban bushland. Austral Ecology 27(5): 573–583.

Kowel, C. (1996) Vegetation Mapping of Wadbilliga National Park. Unpublished report to NSW National Parks And Wildlife Service. Eco Scene Consultants.

Leigh, J. H. & Holgate, M. D. (1979) The responses of the understorey of forests and woodlands of the Southern Tablelands to grazing and burning. *Australian Journal of Ecology* 4, 25–45.

Leishman,M.R., Hughes,M.T. & Gore,D.B. (2004) Soil phosphorus enhancement below stormwater outlets in urban bushland: spatial and temporal changes and the relationship with invasive plants. *Aust.J.Soil Research* 42: 197–202.

Lembit, R. (2001) *Vegetation mapping of Hornsby Shire*. Unpublished report to Hornsby Shire Council by Gingra Environmental Consultants, Campsie.

Lembit, R.S. (2002) *Vegetation Survey of Marramarra National Park, Muogamarra Nature Reserve & Maroota Historic* Site. Report for Sydney North Region, NSW National Parks and Wildlife Service, Mt Colah.

Leonard, G. (1999) *Survey and description of vascular plant species and assemblages, Brush-tailed Rock-wallaby sites, Kangaroo Valley Colony 1, west of Hampden Bridge, Kangaroo Valley, NSW, Australia*. Unpublished report for NSW National Parks and Wildlife Service.

Lewis, P.C. & Glen, R.A. (1995) *Bega-Mallacoota 1:250 000 Geological Sheet SJ/55–04, SJ/55–08*. 2nd Edition. Geological Survey of New South Wales, Sydney.

Lockwood, M., Wise, P., Lane, M., Williams, J., Godd, L. and Costello, D. (1997) *Eurobodalla National Park Flora Survey*. Johnstone Centre of Parks, Recreation and Heritage Report No. 84. CSU Albury Campus Library, Albury.

Lunt I.D. (1991) Management of remnant lowland grasslands and grassy woodlands for nature conservation. *Victorian Naturalist* 108: 56–66.

McIntyre S., Lavorel S. & Tremont R.M. (1995) Plant life-history attributes: their relationship to disturbance response in herbaceaous vegetation. *Journal of Ecology* 83: 31–44.

McDougall, K.L. and Kirkpatrick, J.B. (eds.) (1994) *Conservation of Lowland Native Grasslands in South-eastern Australia.* World Wide Fund for Nature, Australia.

McIlveen, G. (1973) *Ulladulla 1:250 000 Metallogenic Map Sheet SI 56–13*. 1st Edition. Geological Survey of New South Wales, Sydney.

McNellie, M., Greenwood, G., Vanzella, B., Horner, G., Schliebs, M., Turner, B., Davy, M.C., Hudspith, T.J. and Nott, T.A. (2005) *Native vegetation map report series No. 5. Moulamein, Wanganella, Conargo, Cohuna, Mathoura, Tuppal and Echuca 1:100 000 Map Sheets*. NSW Department of Natural Resources, Parramatta.

Miles, J., Maguire, O., Kendall, P. and Graham-Higgs, N. (2001) *Updating of Forest Assemblage Mapping; Tantawangalo and Yurammie Sections of the South East Forests National Park*. Unpublished report to NSW National Parks And Wildlife Service. Nicholas Graham Higgs and Associates.

Miles, J. and Kendall, P. (2001) *Vegetation of Rocky Outcrops South East Forest National Park Bemboka Section*. Unpublished report to NSW National Parks And Wildlife Service.

Miles, J., Maguire, O., Kendall, P. and Graham-Higgs, N. (2002a) *Updating Modeled Boundaries of Forest Ecosystems in Kooraban & Gulaga National Parks Vegetation Survey and Mapping*. Unpublished report to NSW National Parks And Wildlife Service. Nicholas Graham Higgs and Associates.

Miles, J., Maguire, O., Kendall, P. and Graham-Higgs, N. (2002b) *Stage 3 Updating of Forest Assemblage Mapping on NPWS Estate (Bournda and Bermagui Nature Reserves and Bournda, Mimosa Rocks, Biamanga, Gulaga and Wadbilliga National Parks)* Unpublished report to NSW National Parks And Wildlife Service. NGH Environmental.

Miles, J., Kendall, P. and Graham-Higgs, N. (2003) *Stage 4 Updating of Forest Assemblage Mapping on NPWS Estate (Ben Boyd, Mt Imlay, Coolumbooka and Bondi Gulf NPs; Bellbird Creek, Egan's Peak and Nadgee NR's, the Yowaka, Coolangubra, Genoa and Waalimma sections of South East Forests NP*. Unpublished report to NSW National Parks And Wildlife Service. NGH Environmental.

Mills, K. (1993) *The Natural Vegetation of the Jervis Bay Region of New South Wales*. The National Estates Grant Scheme 1990/91. NSW Heritage Assistance Program.

Mills, K. (2000) *Nature Conservation Study, Rural Lands Study Area, City of Shellharbour*, Report prepared for Shellharbour City Council.

Moore,I.D., Gessler,P.E., Nielsen,G.A. & Peterson,G.A. (1993) Soil attribute prediction using terrain analysis. *Soil Science Society of America Journal* 57:443–452.

Morgan J.W. (1997) The effect of grassland gap size on establishment, growth and flowering of the endangered *Rutidosis leptorrhynchoides* (Asteraceae) *Journal of Applied Ecology* 34: 566–576.

Myerscough P. J. & Carolin R. C. (1986) The vegetation of the Eurunderee sand mass, headlands and previous islands in the Myall Lakes area, New South Wales. *Cunninghamia* 1, 399–466.

NGH Environmental (2005) *Vegetation re-mapping for Bungonia State Conservation Area, Bees Nest Nature Reserve and Western Morton National Park*. Unpublished report for NSW NPWS Nowra District.

Nicholson E., Keith D. A. and Wilcove D. S. (2009) Assessing the status of ecological communities. *Conservation Biology*.

Noble, I.R. & Slatyer, R.O. (1981) Concepts and models of succession in vascular plant communities subject to recurrent fire. P.p. 311–335 in Gill A.M., Groves R.H. & Noble I.R. (eds) *Fire and the Australian Biota*. Australian Academy of Science, Canberra.

NPA (1998) *Benandera State Forest Biodiversity Survey*. Unpublished report, National Parks Association, Sydney.

NSW DEC (2004a) *Flora Online*. Botanic Gardens Trust. http://plantnet.rbgsyd.gov.au.

NSW DEC (2004b) *Eastern Suburbs Banksia Scrub Endangered Ecological Community Recovery Plan*. NSW Department of Environment and Conservation.

NSW DEC (2004c) *The Native Vegetation of the Nattai and Bargo Reserves*. Unpublished report. NSW Department of Environment & Conservation, Hurstville.

NSW DLWC (1999) *Soil and Regolith Attributes for CRA/RFA Model Resolution (Southern Regions)* NSW Department of Urban Affairs and Planning: Sydney.

NSW DLWC (2002) *Soil Landscapes of the Sydney Catchment Authority Hydrological Catchments*. A joint project undertaken by NSW Department of Land & Water Conservation and Sydney Catchment Authority.

NSW DNR (2006) *NSW Comprehensive Coastal Assessment Project 5 Report: Soil and Land Assessment*. NSW Department of Natural Resources, Parramatta.

NSW DUAP (1999) CRAFTI Southern Region Report. NSW Department of Urban Affairs and Planning, Sydney.

NSW NPWS (2000a) *Vegetation Survey, Classification and Mapping: Lower Hunter and Central Coast Region*. A project undertaken for the LHCC Regional Environmental Management Strategy. NSW National Parks and Wildlife Service.

NSW NPWS (2000b) *Biodiversity Study for the Georges River Catchment. Volume 1: Native Vegetation*. Background study for Stage 2 of the Georges River Catchment Regional Environmental Plan, prepared for Department of Urban Affairs & Planning by NSW National Parks and Wildlife Service, Hurstville.

NSW NPWS (2000c) *Terrestrial Ecosystems of the Eurobodalla Local Government Area*. A project undertaken with Eurobodalla Council and the Lower South Coast Catchment Management Committee by NSW National Parks and Wildlife Service.

NSW NPWS (2000d) Unpublished survey data. Southern CRA vegetation surveys 1997 – 2000. NSW National Parks and Wildlife Service, Queanbeyan.

NSW NPWS (2001) Unpublished data, for survey of Umina Coastal Sands Woodland for nomination before Scientific Committee. NSW National Parks and Wildlife Service.

NSW NPWS (2002) *Native Vegetation of the Illawarra Escarpment and Coastal Plain*. Bioregional Assessment Study Part I. (NSW National Parks and Wildlife Service: Hurstville)

NSW NPWS (2003a) *The Native Vegetation of the Warragamba Special Area*. Report to the Sydney Catchment Authority. (NSW National Parks and Wildlife Service: Hurstville)

NSW NPWS (2003b) *The native vegetation of the Woronora, O'Hares and Metropolitan Catchments*. Unpublished report to the Sydney Catchment Authority. NSW National Parks and Wildlife Service, Hurstville.

NSW Scientific Committee (undated) Schedules of the Threatened Species Conservation Act maintained by the NSW Scientific Committee. http://www.environment.nsw.gov.au/committee/SchedulesThreatenedSpeciesConservationAct.htm

Payne R. (undated) Unpublished vegetation plot data from Umina High.

Payne, R. (1996) Unpublished vegetation plot data from Bouddi Peninsula.

Peake, T.C. (2005) *The Vegetation of the Central Hunter Valley, New South Wales*. A Report on the Findings of the Hunter Remnant Vegetation Project. Hunter – Central Rivers Catchment Management Authority, Paterson

Pellow, B.J. & French, K.R. (2003) *Flora study of the Defence Establishment, Orchard Hills*. Janet Cosh Herbarium, University of Wollongong: Wollongong.

Pogson, D.J. & Watkins, J.J. (eds) (1998) *Bathurst 1:250 000 Geological Sheet SI 55 – 08*. Explanatory Notes. Geological Survey of New South Wales, Sydney.

Poore, M.E.D. (1955) The use of phytosociological methods in ecological investigations: I. The Braun-Blanquet system. *Journal of Ecology* 43: 226–244.

Pressey R.L. (1989) Wetlands of the lower Clarence floodplain, northern coastal New South Wales. *Proceedings of the Linnean Society of New South Wales* 111: 143–155.

Prober S.M. and Thiele K.R. (1995) Conservation of Grassy White Box Woodlands: Relative contributions of size and disturbance to floristic composition and diversity of remnants. *Australian Journal of Botany* 43: 349–366.

Proust Bushland Surveys (2002) *Unpublished vegetation survey of Barren Grounds Nature Reserve*. NSW National Parks and Wildlife Service.

Raymond, O.L. & Pogson, D.J. (1998) *Bathurst 1:250 000 Geological Sheet SI 55 – 08*. 2nd Edition. Geoscience Australia, Canberra and Geological Survey of New South Wales, Sydney.

RBG (1974–1987) Miscellaneous unpublished vegetation survey data Ku-ring-gai Chase NP. Royal Botanic Gardens, Sydney.

Richardson DM, Pyusek P, Rejmànek M, Barbour MG, Panetta FD, West CJ (2000) Naturalisation and invasion of alien plants: concepts and definitions. *Diversity and Distributions* 6, 93–107.

Rodwell,J.S., Schaminée,J.H.J., Mucina,L. Pignatti,S., Dring,J. and Moss,D. (2002) *The diversity of European vegetation. An overview of phytosociological alliances and their relationships to EUNIS habitats*. National Reference Centre for Agriculture, Nature and Fisheries, Wageningen, NL.

Rose, G. (1966a) *Wollongong 1:250 000 Geological Sheet SI/56–09*. 2nd Edition. Geological Survey of New South Wales, Sydney.

Rose, G. (1966b) *Ulladulla 1:250 000 Geological Sheet SI/56–13*. 1st Edition. Geological Survey of New South Wales, Sydney.

Scheibner, E. (1973) *Taralga 1:100 000 Geological Series Sheet 8829*. 1st edition. Geological Survey of New South Wales, Sydney.

Sheringham, P.R. and Sanders, J. (1993) *Vegetation Survey of Garigal National Park and surrounding crown lands*. Unpublished report. NSW National Parks and Wildlife Service.

Sivertsen, D. & Metcalfe,L.(1995) *Natural vegetation of the southern wheat-belt (Forbes and Cargelligo 1:250 000 map sheets) Cunninghamia* 4, 103–128.

Sivertsen, D.P. & Smith, P.L. (eds) (2001) *Guidelines for mapping native vegetation: Version 2.1 – Guidelines and Appendices*. Unpublished report. New South Wales Department of Land and Water Conservation, Sydney.

Skelton, N. (2004) *Flora and Fauna Survey and Management Recommendations for Sydney Harbour National Park (Dobroyd Head)* Report to NSW NPWS by GIS Environmental Consultants, Sydney

Skelton, N.J. and Adam, P. (1994) *Beecroft Peninsula Vegetation Survey*. Australian Nature Conservation Agency, Canberra.

Skelton, N. & Gilson, T. (2004) *Verification and Modification of the Vegetation Map for the Beecroft Weapons Range, Jervis Bay*. Unpublished report by GIS Environmental Consultants, Sydney.

Skelton, N., Richmond, O., Gilson, T. and Wong, P. (2003) *Flora of North Head including the lands at the Former School of Artillery, the Royal Australian Artillery National Museum, Sydney Harbour National Park and the Australian Institute of Police Management*. Report to the Sydney Harbour Federation Trust by GIS Environmental Consultants, Sydney.

Skidmore, A.K. (1990) Terrain position as mapped from a grided digital elevation model. *International Journal of Geographic Information Systems* 4(1): 33–49

Smith, P. and Smith, J. (2000) *Survey of the Duffys Forest vegetation community*. Report to NSW NPWS & Warringah Council. P. & J. Smith Ecological Consultants, Blaxland.

Smith, P. and Smith, J. (2003) *Warringah Natural Area Survey: Vegetation communities and plant species*. A report prepared for Warringah Council.

Smith, P.J. and Smith, J.E. (1996) *Vegetation Survey of the Kedumba Valley*. Unpublished report to Sydney Catchment Authority.

Stern, H., de Hoedt, G. and Ernst J. (1999) Objective classification of Australian climates. *8th Conf. on Aviation, Range and Aerospace Meteorology*, Amer. Meteor. Soc., Dallas, Texas, 10–15 Jan., 1999.

Stevens, B. (1968) *Bathurst 1:250 000 Metallogenic Map Sheet SI 55–08*. 1st Edition. Geological Survey of New South Wales, Sydney.

Taws, N. (1997) *Vegetation Survey and Mapping of Jervis Bay Territory*. A report to Environment Australia, Canberra.

Thackway, R. & Cresswell, I.D. (1995) *An Interim Biogeographic Regionalisation for Australia: A Fframework for Setting Priorities in the National Reserves System Cooperative Program*. Version 4.0 (Australian Nature Conservation Agency: Canberra)

Thomas D. (2001) Unpublished Vegetation Survey Data, Warragamba catchment. Collected for the Sydney Catchment Authority.

Thomas, D. (undated) Unpublished vegetation survey data.

Thomas, V., Gellie, N. and Harrison, T. (2000) *Forest Ecosystem Classification and Mapping for the Southern CRA Region*. Report for the NSW CRA/RFA Steering Committee, Project No. NS 08EH. (NSW National Parks and Wildlife Service: Queanbeyan)

Tindall, D., Pennay, C, Tozer, M. Turner, K. & Keith, D. (2004) *Native vegetation map report series. No. 4*. (Department of Infrastructure Planning and Natural Resources: NSW)

Togher, C. (1996) *A Report on the Biodiversity and Land Management of the Abercrombie River Catchment*. National Parks Association Inc., Sydney.

Tozer, M. (2003) The native vegetation of the Cumberland Plain, western Sydney: systematic classification and field identification of communities. *Cunninghamia* 8(1): 1–75.

Tozer,M.G. (in press) How similar is Cumberland Plain Woodland to other coastal valley grassy woodlands in NSW? Royal Zoological Society of NSW

Tozer, M. G., Turner, K., Simpson, C. C., Keith, D. A., Beukers, P., Mackenzie, B., Tindall, D. & Pennay, C. (2006) *Native Vegetation of Southeast NSW: A Revised Classification and Map for the Coast and Eastern Tablelands*. Version 1.0. Department of Environment & Conservation and Department of Natural Resources, Sydney.

Turner, K. and Crooks, J. (undated) Unpublished data from Southern Tablelands Property Agreement Monitoring Project, NSW Department of Land and Water Conservation.

Urban Bushland Management Consultants (1998) *Elderslie Banksia Scrub-Woodland Rehabilitation Plan*. Report to Landcom.

Vickery J.W. (1961) *Themeda*. Gramineae. *NSW Flora Series* 19: 59–61.

Wall, J. (2006) *Nandewar biodiversity surrogates – vegetation*. NSW Department of Environment and Conservation, Armidale.

Walsh, N.G., Barley, R.H., Gullan, P.K. (1983) *Alpine vegetation: sites of botanical significance in the Victorian alps, excluding Bogong High Plains* (National Herbarium of Victoria: Melbourne)

Walter, K. & Schelling, K. (2004) *Remote sensing mapping of grassy ecosystems in the Monaro*. Report to the NSW Department of Environment and Conservation, Queanbeyan

Walter, K. & Schelling, K. (2005) *Remote sensing mapping of grassy ecosystems in the upper catchment of the Shoalhaven River (Southern tablelands section)* Report to the NSW Department of Environment and Conservation, Queanbeyan.

Whelan, R.J., Rodgerson, L., Dickman, C.R. & Sutherland, E.F. (2002) Critical life cycles of plants and animals: developing a process-based understanding of population changes in fire-prone landscapes. pp. 94–124 in: Bradstock, R.A., Williams, J. and Gill, A.M. (eds) *Flammable Australia: The Fire Regimes and Biodiversity of a Continent*. Cambridge University Press, Cambridge.

West,R.J., Thorogood,C.A., Walford,T.R. and Williams, R.J. (1985) An Estuarine Inventory for New South Wales, Australia. *Fisheries Bulletin* 2. Department of Agriculture, New South Wales.

Westbrooke, M.E., Miller, J.D. and Kerr, M.K.C. 1998. The vegetation of the Scotia 1: 100 000 map sheet, western New South Wales. *Cunninghamia* 5(3): 665–684.

Westhoff, V. and van der Maarel, E. (1978) The Braun-Blanquet approach. pp. 287–328 in Whittaker, R.H. (ed) *Classification of plant communities*. Junk, The Hague.

Whinam, J. and Chilcott, N. (2002) Floristic description and environmental relationships of *Sphagnum* communities in NSW and the ACT and their conservation and management. *Cunninghamia* 7(3): 463–500

Williams, J. (1997) *Vegetation survey of Bermagui Nature Reserve, Biamanga National Park, Goura Nature Reserve and Wallaga National Park*. Unpublished report to NSW National Parks and Wildlife Service, Narooma District.

Wimbush, D.J. & Costin, A.B. (1979) Trends in vegetation at Kosciusko: 1. Grazing trails in the subalpine zone, 1957–1971. *Australian Journal of Botany* 27: 741–787

Woodgate, P.W., Peel, W.D., Ritman, K.T., Coram, J.E., Brady, A., Rule, A.J. & Banks, J.C.G. (1994) *A study of the old growth forests of East Gippsland*. Victorian Department of Conservation and Natural Resources, Melbourne.

Wyborn, D. & Owen, M. (1982) *Araluen 1:100 000 Geological Series Sheet 8826*. 1st Edition. Bureau of Mineral Resources, Geology & Geophysics, Department of Resources & Energy, Canberra.

Manuscript accepted 16 February 2010

Appendix 1: Map Unit Habitat Characteristics

The following table summarises elevation, climate and lithology data for the field survey sites allocated to each map unit. Data were derived in a geographic information system by intersecting the locations of classified sites against spatial environmental data layers (see Table 4).

Values given for elevation, rainfall and temperatures are (minimum) 25th percentile – 75th percentile (maximum). Lithology indicates the mapped lithological classes which the field samples for each map unit were most frequently located on (ae=aeolian sediments; al=alluvium, gr=granitic; hqs=high-quartz sedimentary; ia=inactive alluvium; li=limestone; lqs=low-quartz sedimentary; ma=marine/coastal sands; mf=transitional sedimentary; va=acid volcanic; vb=basaltic; xx=excavated/filled land; and water=water bodies including rivers and lakes).

Map Unit	n	Elevation (metres above sea level)	Average Annual Rainfall (mm)	Maximum Temp. of Warmest Period (degC)	Minimum Temp. of Coldest Period (degC)	Soil Landscape Lithology (% frequency)
e1	22	(16) 213-377 (569)	(784) 903-964 (1057)	(23.5) 24-24.3 (25.3)	(0.3) 0.9-2.4 (5)	gr(82) lqs(14) hqs(5)
e3	18	(90) 268-548 (784)	(773) 952-1047 (1082)	(22.6) 23.2-24 (25.6)	(-0.4) 0.3-2.4 (3.7)	gr(56) hqs(33) lqs(11)
e4	14	(85) 321-462 (634)	(917) 950-1012 (1087)	(23.2) 24.2-25 (25.2)	(-0.2) 0.5-1.2 (2)	lqs(57) hqs(43)
e6e7	88	(13) 220-432 (675)	(839) 938-1035 (1229)	(21.2) 23.6-24.7 (25.6)	(-0.4) 0.8-3.1 (6)	lqs(38) gr(36) hqs(18)
e9	12	(797) 840-1000 (1030)	(1056) 1071-1238 (1267)	(20.7) 20.7-22.9 (23.2)	(-1.7) -1--0.6 (-0.5)	gr(92) lqs(8)
e10	100	(183) 735-919 (1185)	(808) 1049-1104 (1311)	(20.8) 22.3-23.1 (24.8)	(-1.6) -1--0.1 (3)	gr(87) lqs(4) al(3) hqs(3)
e11	23	(752) 856-910 (945)	(885) 1087-1108 (1139)	(22.2) 22.5-22.7 (23.2)	(-1.1) -0.8--0.6 (-0.4)	gr(96) hqs(4)
e12	95	(165) 588-789 (1060)	(841) 996-1091 (1296)	(21.3) 23-23.7 (24.8)	(-1.3) -0.3-0.8 (5.4)	gr(55) lqs(22) va(14)
e13	65	(6) 144-450 (839)	(833) 922-1018 (1318)	(21) 23.6-24.3 (25.2)	(-0.4) 1.1-2.7 (6.9)	gr(46) lqs(23) hqs(17)
e14	46	(59) 295-482 (700)	(863) 1000-1131 (1221)	(21.5) 22.2-23.4 (25)	(0.6) 1.7-2.7 (6)	hqs(50) gr(24) lqs(20)
e15	139	(267) 613-845 (1127)	(911) 1036-1116 (1390)	(19.7) 22.1-23.2 (24.5)	(-1.2) -0.6-0.4 (1.8)	gr(94) lqs(4) hqs(1) va(1)
e17	28	(93) 483-565 (922)	(895) 959-1001 (1082)	(22.5) 23.3-23.7 (24.2)	(-1) 0.2-0.8 (4.6)	gr(93) lqs(7)
e18	28	(104) 161-254 (802)	(846) 942-1019 (1091)	(22.6) 24.5-25 (25.3)	(-0.3) 1.5-2 (4.5)	gr(86) lqs(7) hqs(4) vb(4)
e19	95	(4) 125-246 (482)	(763) 869-984 (1081)	(23.3) 24.6-25.2 (26.1)	(0.2) 1.6-2.2 (4)	gr(61) lqs(23) al(5)
e20p229	128	(7) 101-204 (862)	(566) 815-980 (1049)	(23.8) 24.7-25.6 (26.3)	(-1.8) 1.5-2.2 (4.5)	gr(69) lqs(25) al(3) hqs(3)
e24	32	(772) 948-1090 (1210)	(769) 874-1031 (1184)	(21.3) 22.2-22.6 (23.6)	(-2) -1.3--1.1 (-0.8)	gr(59) lqs(28) hqs(9)
e25	11	(370) 798-887 (1040)	(920) 1089-1216 (1256)	(20.7) 21.3-22.2 (24)	(-1.7) -0.6--0.5 (1.2)	lqs(91) gr(9)
e26	38	(273) 390-704 (870)	(897) 949-1020 (1104)	(22.1) 23-23.3 (24.2)	(-1.2) 0-1.7 (2.7)	gr(71) lqs(29)
e27	7	(330) 360-396 (501)	(987) 1003-1029 (1091)	(22.6) 22.9-23.1 (23.2)	(1.5) 1.8-2.3 (2.5)	gr(100)
e28	11	(424) 456-488 (491)	(903) 919-942 (1064)	(23.3) 23.9-24.1 (24.2)	(0.6) 0.6-0.8 (1.1)	gr(100)
e29	19	(392) 535-655 (731)	(927) 963-1041 (1172)	(22.1) 23.2-23.7 (24.1)	(-0.8) 0-0.6 (1.7)	gr(89) lqs(11)
e30	11	(11) 207-424 (610)	(839) 941-1009 (1084)	(22.5) 23.1-23.7 (24.6)	(0.1) 1.7-3.3 (5)	gr(45) hqs(18) lqs(18) va(18)
e31	56	(145) 389-570 (916)	(858) 914-1044 (1138)	(22.3) 23.1-24.1 (24.3)	(-1.2) 0.6-1.2 (2.9)	gr(95) lqs(5)
e32a	93	(23) 78-221 (647)	(876) 988-1048 (1100)	(23.7) 24.1-24.3 (25.7)	(-0.2) 2.5-3.9 (4.5)	lqs(73) hqs(23) gr(4)
e32b	45	(12) 80-179 (375)	(884) 945-1011 (1071)	(21.5) 24-24.3 (24.6)	(2) 2.5-3.4 (5.4)	lqs(51) hqs(24) va(18)
e33	32	(54) 278-385 (641)	(863) 964-1037 (1226)	(21.5) 23.2-23.9 (24.2)	(0.4) 1.7-2.5 (4)	lqs(41) gr(28) hqs(25)

Map Unit	n	Elevation (metres above sea level)	Average Annual Rainfall (mm)	Maximum Temp. of Warmest Period (degC)	Minimum Temp. of Coldest Period (degC)	Soil Landscape Lithology (% frequency)
e34	49	(9) 51-163 (426)	(849) 958-1019 (1101)	(23.1) 24.2-24.7 (25.2)	(1.2) 2.2-3.7 (5.5)	lqs(78) hqs(12) gr(6)
e35	59	(32) 280-466 (756)	(806) 893-1050 (1149)	(22.8) 23.7-24.5 (25.2)	(0) 1-1.9 (3.5)	gr(68) lqs(27) hqs(3)
e37	20	(2) 9-127 (262)	(838) 892-992 (1062)	(21.2) 21.8-23.2 (24.5)	(2.5) 4.6-6.2 (7.1)	hqs(60) lqs(30) ma(10)
e38	5	(12) 26-325 (369)	(842) 885-919 (958)	(22.5) 23.2-24 (24.2)	(1.1) 2.2-5.1 (6)	gr(40) al(20) hqs(20) lqs(20)
e39	14	(30) 100-202 (269)	(783) 798-855 (951)	(24.6) 24.7-25.5 (25.8)	(1.1) 1.3-2.4 (3.5)	al(57) gr(29) hqs(7) lqs(7)
e42	67	(94) 354-516 (938)	(932) 1018-1112 (1242)	(20.7) 22.6-23.2 (24.2)	(-0.3) 1.3-2.3 (5.1)	gr(64) hqs(13) va(13)
e43	15	(100) 490-733 (942)	(905) 980-1130 (1158)	(21.3) 22.2-23.5 (24.1)	(-0.8) -0.2-0.8 (4.3)	lqs(80) gr(20)
e44	42	(91) 601-833 (1006)	(874) 1033-1107 (1202)	(21.2) 22.2-23.1 (24)	(-1.3) -0.6-0.5 (3.7)	gr(79) lqs(14) hqs(7)
e45	29	(16) 595-911 (1007)	(911) 1006-1102 (1240)	(20.7) 22.1-23.1 (23.7)	(-1.2) -1-0.2 (7)	gr(86) hqs(7) lqs(7)
e46b	25	(16) 49-114 (169)	(860) 886-983 (1044)	(21.8) 22.8-24.2 (24.7)	(2.5) 3.7-4.9 (6.9)	hqs(64) lqs(24)
e47	22	(20) 117-499 (789)	(867) 960-1146 (1389)	(20.3) 21.2-22.1 (23.8)	(1.1) 2.1-5 (7.3)	hqs(82) lqs(14) ae(5)
e48	15	(118) 212-446 (548)	(1012) 1040-1132 (1171)	(22.8) 23.2-24 (24.6)	(1.3) 1.7-2.4 (2.7)	gr(100)
e49	43	(56) 245-537 (888)	(893) 952-1099 (1201)	(21.7) 22.8-23.7 (24.7)	(-0.6) 1.4-2.7 (4.8)	hqs(37) va(37) gr(12)
e50	7	(325) 368-570 (725)	(903) 931-978 (1008)	(22.8) 23.3-23.7 (24.1)	(-0.8) 0.3-1.2 (2.7)	lqs(57) gr(29) hqs(14)
e51	16	(141) 216-394 (613)	(896) 948-1063 (1211)	(21.8) 22.8-23.7 (24)	(1.5) 2-3 (3.4)	va(81) hqs(13) al(6)
e52	8	(591) 654-776 (1020)	(1057) 1169-1215 (1232)	(20.7) 21.6-22.2 (23)	(-1.1) -0.4-0.7 (1.1)	gr(100)
e53	30	(525) 762-1055 (1226)	(575) 886-1007 (1194)	(20.6) 22.2-23.8 (25.1)	(-1.7) -1.3--0.6 (0.6)	hqs(43) lqs(43) gr(7) va(7)
e54	18	(33) 82-445 (527)	(892) 931-1209 (1271)	(20.2) 20.6-21.6 (22.6)	(3.4) 3.9-5.7 (7)	hqs(100)
e55	25	(16) 23-44 (76)	(851) 875-919 (924)	(21.3) 21.7-22.7 (24.3)	(3.5) 5.3-6.9 (7.3)	hqs(92) al(4) va(4)
e56	13	(48) 153-374 (666)	(872) 950-1003 (1022)	(22.7) 23.1-23.3 (23.5)	(0) 2.2-3.9 (5.4)	gr(62) al(38)
e57	19	(3) 25-198 (516)	(869) 912-1059 (1262)	(20.3) 21.2-21.7 (23.2)	(3.5) 5-7 (7.1)	hqs(68) ae(11) al(11)
e59	18	(768) 935-1100 (1183)	(854) 1001-1082 (1238)	(20.7) 21.7-22.5 (23.2)	(-2) -1.3--1 (-0.5)	gr(56) al(22) lqs(17)
e60	11	(6) 7-72 (148)	(860) 863-880 (897)	(23.7) 24.7-25.2 (25.2)	(2.2) 2.4-2.7 (4.8)	al(73) gr(18) lqs(9)
e61	31	(0) 2-4 (11)	(840) 856-955 (1228)	(21.5) 23.7-24.6 (25)	(3.5) 3.9-6 (7.4)	ma(83) ae(9)
e62	26	(0) 2-3 (6)	(840) 858-953 (1266)	(21.5) 23.7-24.6 (25.5)	(3.5) 3.7-5.5 (7.4)	ma(90) water(7) gr(3)
e46a	20	(147) 196-329 (358)	(939) 958-999 (1036)	(22.6) 22.8-23.2 (23.5)	(2.2) 2.7-3.6 (4)	gr(90) al(5) hqs(5)
e81	20	(64) 761-935 (1037)	(870) 1011-1127 (1202)	(21.6) 22.7-23.4 (24.7)	(-1.2) -1--0.1 (3.2)	lqs(50) hqs(45) gr(5)
e83	15	(1085) 1156-1273 (1333)	(1061) 1101-1228 (1288)	(19.7) 20.3-21.2 (21.8)	(-1.8) -1.7--1.5 (-1.3)	hqs(100)
e85	34	(62) 187-336 (615)	(849) 910-941 (1015)	(24.2) 25.2-25.7 (26.2)	(0) 0.7-1.5 (2.5)	gr(53) lqs(38) al(6)
m15	8	(6) 7-41 (60)	(837) 849-876 (901)	(22.5) 22.7-23.7 (24.2)	(4) 4.5-5.8 (6)	hqs(63) ma(38)
m68	20	(675) 854-1023 (1292)	(533) 802-912 (972)	(21.7) 22.6-23.5 (25.8)	(-2.9) -1.6--1.1 (0)	gr(55) lqs(20) vb(15)
m83	9	(2) 7-21 (29)	(840) 844-921 (931)	(21.3) 21.6-22.7 (24.6)	(3.7) 6-7.1 (7.4)	hqs(56) ae(22) ma(22)
n183	76	(8) 131-401 (745)	(857) 1000-1075 (1164)	(22.2) 24.1-24.7 (26)	(-0.1) 2-3.5 (5.1)	lqs(55) hqs(21) gr(13)
n184	33	(7) 101-293 (474)	(848) 980-1093 (1234)	(23.1) 23.8-24.7 (26.2)	(0.6) 2.4-3.7 (5.5)	lqs(55) gr(36) hqs(6)
p50	2	(10) 192-557 (739)	(1099) 1123-1170 (1193)	(25) 25.3-25.9 (26.2)	(1) 2.3-4.8 (6.1)	hqs(100)
p1	42	(1) 19-46 (84)	(803) 824-898 (1158)	(25.8) 27.2-28.7 (29.1)	(3.2) 3.6-5 (6.8)	al(48) lqs(31) mf(7) xx(7)
p2	79	(10) 113-199 (370)	(790) 855-902 (1094)	(25.8) 26.7-27.7 (28.7)	(1.7) 2.7-3.7 (4.9)	lqs(62) mf(24) hqs(14)
p3	19	(5) 9-22 (250)	(889) 1043-1163 (1249)	(23.7) 24.1-25.5 (25.8)	(2.2) 4.7-7.1 (7.4)	hqs(42) gr(37) al(11) lqs(11)

Map Unit	n	Elevation (metres above sea level)	Average Annual Rainfall (mm)	Maximum Temp. of Warmest Period (degC)	Minimum Temp. of Coldest Period (degC)	Soil Landscape Lithology (% frequency)
p4	7	(12) 18-38 (60)	(746) 808-843 (869)	(27.3) 27.7-28.9 (29.1)	(2.9) 3.5-4.4 (4.8)	al(71) ae(14) lqs(14)
p5	56	(120) 164-410 (623)	(780) 843-900 (1015)	(26.2) 27.5-28.6 (29.2)	(0.6) 1.2-1.8 (2.2)	lqs(52) hqs(46) gr(2)
p6	25	(26) 128-585 (953)	(801) 842-952 (1242)	(23.7) 26.3-29 (29.2)	(0.2) 1.7-3 (5.3)	hqs(40) lqs(40) mf(12)
p7	25	(7) 30-39 (63)	(807) 824-829 (899)	(27.1) 28.7-28.8 (29)	(3.2) 3.4-3.5 (5.1)	al(96) lqs(4)
p8	84	(628) 842-988 (1217)	(732) 856-967 (1183)	(21.6) 23.5-24.6 (26.2)	(-2.2) -0.8-0.1 (1.3)	lqs(46) va(25) hqs(19)
p9	42	(556) 610-695 (802)	(650) 691-754 (897)	(24.7) 25.9-26.5 (26.7)	(-0.6) 0.4-1.2 (1.5)	lqs(48) ia(24) gr(14)
p10	63	(263) 664-774 (906)	(695) 741-842 (959)	(24.2) 25.5-26.1 (26.6)	(-0.1) 0.2-1.2 (1.8)	lqs(51) hqs(38) ia(5)
p11	63	(400) 600-725 (853)	(702) 770-870 (980)	(25.2) 25.7-26.3 (27.8)	(0) 0.6-1.2 (2)	lqs(67) hqs(27) va(3)
p14	143	(516) 708-882 (1160)	(672) 720-793 (1035)	(22.2) 25.2-26.6 (28.5)	(-1.2) -0.4-0.1 (0.8)	lqs(82) gr(6) va(6) vb(6)
p15	40	(210) 610-719 (1076)	(669) 780-876 (1030)	(22.5) 24.7-25.4 (26.3)	(-1.6) -0.6-0.7 (1.7)	lqs(40) ia(23) hqs(18) va(18)
p17	7	(624) 748-971 (1072)	(589) 763-918 (930)	(23.2) 24.1-25.2 (26.1)	(-1.5) -0.4-0.7 (0.8)	lqs(57) al(14) gr(14) va(14)
p19	36	(532) 590-769 (1040)	(687) 723-751 (866)	(23.8) 26.4-27.4 (28.2)	(-0.6) -0.1-0.3 (1.5)	lqs(83) va(8) gr(6)
p20	28	(595) 731-951 (1272)	(769) 818-981 (1114)	(21.6) 24.6-25.1 (26)	(-1) -0.4-1.2 (2.2)	vb(68) lqs(25) ia(4) water(4)
p22	68	(586) 676-806 (1140)	(641) 696-809 (958)	(22.3) 25-26.3 (27.1)	(-2.7) -0.4-0.2 (1.2)	lqs(29) gr(22) ia(21)
p23	119	(523) 652-887 (1127)	(664) 711-820 (940)	(23.1) 25.1-26.5 (27.2)	(-1.6) -0.4-0.8 (1.6)	lqs(47) gr(17) va(12)
p24	78	(611) 676-788 (916)	(664) 688-767 (923)	(24.8) 26-26.7 (27.6)	(-0.4) 0-0.5 (1.6)	lqs(47) gr(26) ia(10)
p27	13	(330) 492-561 (600)	(704) 712-723 (771)	(25.7) 26-26.7 (27.6)	(1.2) 1.3-1.7 (2.2)	lqs(85) li(15)
p28	44	(50) 74-150 (328)	(752) 789-827 (885)	(26.6) 27.5-27.9 (28.7)	(1.7) 2.7-3.2 (4)	lqs(93) al(7)
p29	150	(1) 37-89 (390)	(739) 818-859 (953)	(25.8) 27.5-28.5 (29.1)	(1.2) 3.2-4 (5.6)	lqs(73) al(20) mf(3)
p30	39	(2) 10-92 (286)	(825) 974-1091 (1243)	(23.7) 24.4-25.5 (29.2)	(1.3) 3.5-4.9 (7)	lqs(54) al(13) hqs(13)
p31	16	(120) 128-158 (564)	(813) 830-854 (964)	(26.6) 28.7-29.2 (29.2)	(0.8) 2-2 (2.7)	lqs(75) al(13) hqs(6) vb(6)
p32	41	(15) 76-251 (562)	(688) 793-1032 (1289)	(25) 26.2-28.7 (29.5)	(1) 1.7-4 (7.3)	al(32) hqs(22) lqs(22)
p33	74	(1) 15-154 (398)	(732) 803-867 (1100)	(26.6) 27.4-28.6 (29.1)	(1.6) 2.7-4.1 (5.1)	al(51) lqs(27) mf(13)
p34	39	(5) 24-142 (357)	(964) 1158-1398 (1818)	(23.7) 24.8-25.3 (28)	(3.5) 5.5-7 (7.8)	lqs(38) hqs(31) vb(21)
p35	94	(130) 307-589 (836)	(695) 735-804 (1018)	(25.1) 26.5-28.2 (29.1)	(0.2) 1-1.7 (4.9)	va(74) gr(11) lqs(11)
p36	55	(114) 232-465 (803)	(741) 821-884 (1025)	(24.7) 27.2-28.7 (29.2)	(0.6) 1.1-1.6 (3.4)	lqs(65) va(15) hqs(13)
p37	58	(190) 550-695 (847)	(764) 829-934 (1019)	(24.7) 25.5-26.7 (28.5)	(0.3) 0.6-1 (2.2)	va(43) lqs(29) gr(17)
p38	47	(10) 189-408 (808)	(740) 792-861 (1085)	(24.5) 27.2-28.5 (29.3)	(0.8) 1.2-2 (4.3)	lqs(47) va(23) gr(9) hqs(9)
p39	9	(140) 227-275 (499)	(795) 831-874 (901)	(26.5) 26.7-27.3 (28.2)	(1.2) 1.7-2 (3.5)	lqs(78) gr(11) hqs(11)
p40	124	(2) 61-203 (581)	(795) 972-1046 (1254)	(23.5) 24.3-25.3 (29.3)	(0.6) 2.5-4 (6.3)	lqs(61) hqs(20) gr(8)
p44	15	(4) 10-24 (186)	(869) 902-928 (1261)	(26.2) 28.1-28.2 (28.5)	(2.5) 4.4-4.5 (5.6)	hqs(40) al(27) mf(20)
p45	18	(2) 3-10 (56)	(1151) 1207-1258 (1301)	(24.2) 24.9-25.4 (26.3)	(5.6) 6-7.5 (8.1)	ma(39) hqs(22)
p46	3	(104) 122-160 (181)	(1251) 1353-1484 (1514)	(24.7) 24.7-24.7 (24.7)	(5) 6-7 (7)	vb(67) gr(33)
p51	2	(673) 673-673 (673)	(694) 694-694 (694)	(26.3) 26.3-26.3 (26.3)	(0.2) 0.2-0.2 (0.2)	water(100)
p53	12	(532) 556-673 (1081)	(696) 801-961 (1140)	(22.7) 25.4-26.3 (26.7)	(-0.1) 0.9-1.6 (2)	al(42) hqs(25) ia(17)
p54	17	(606) 675-807 (1109)	(668) 860-915 (979)	(22.5) 24.6-25.5 (26.2)	(-0.8) -0.6-0.5 (1.7)	lqs(35) hqs(24) va(24)
p55	6	(30) 156-789 (936)	(703) 721-832 (908)	(25) 25.3-27.8 (28.2)	(-0.4) 0.2-1.8 (4)	al(33)
p56	8	(492) 704-925 (977)	(605) 734-931 (1032)	(22.6) 23-25.2 (25.7)	(-1.6) -1.2--0.7 (0.6)	al(50) gr(50)

Map Unit	n	Elevation (metres above sea level)	Average Annual Rainfall (mm)	Maximum Temp. of Warmest Period (degC)	Minimum Temp. of Coldest Period (degC)	Soil Landscape Lithology (% frequency)
p57	16	(4) 310-645 (915)	(788) 885-1097 (1290)	(23.2) 23.5-25.9 (27.7)	(-0.4) 0.6-2.4 (6.9)	**al(56) gr(25) hqs(13)**
p58	22	(10) 47-258 (413)	(836) 905-1144 (1452)	(24.6) 25.9-27.2 (29.2)	(1.6) 3.1-5 (6.4)	hqs(86) lqs(14)
p63	31	(1) 5-21 (175)	(998) 1205-1304 (1475)	(23.6) 24.6-25.5 (25.7)	(4.6) 6.5-7.3 (8.3)	hqs(47) ae(16) ma(16)
p64	65	(0) 4-22 (130)	(847) 1194-1291 (1476)	(23.6) 24.3-25.2 (27.2)	(3.5) 5.8-7.5 (8.1)	ma(33) ae(26) hqs(26)
p66	56	(161) 587-817 (1108)	(744) 821-972 (1195)	(22.7) 24.5-26.1 (27.5)	(-0.8) 0.3-1.6 (2.5)	lqs(52) va(16) hqs(14)
p68	8	(339) 395-473 (477)	(930) 1028-1176 (1189)	(25.1) 25.2-25.4 (25.7)	(2.5) 2.7-3.3 (3.7)	hqs(75) mf(25)
p72	21	(427) 907-993 (1028)	(930) 1245-1336 (1358)	(22.5) 22.8-23.5 (27.2)	(0.5) 0.8-1 (1.8)	vb(67) hqs(24) gr(5) lqs(5)
p73	99	(667) 911-1161 (1280)	(761) 908-991 (1073)	(21.3) 22.3-24.3 (26.3)	(-1.8) -0.6--0.2 (0.4)	lqs(55) va(18) gr(14)
p76	14	(646) 847-989 (1106)	(1016) 1082-1171 (1322)	(22.2) 23-24 (25.6)	(0.1) 0.3-0.8 (1.1)	lqs(64) hqs(29) va(7)
p78	65	(620) 871-1118 (1285)	(859) 1095-1243 (1369)	(20.2) 21-22.3 (23.5)	(-1.8) -1.3--0.6 (2.2)	gr(45) hqs(43) lqs(11)
p84	3	(159) 163-304 (442)	(893) 895-947 (997)	(25.7) 26.3-26.9 (27)	(2.9) 3.5-4 (4)	lqs(100)
p85	43	(9) 19-53 (98)	(1067) 1130-1227 (1346)	(24.1) 24.7-25.6 (26.5)	(4) 6-7.1 (8.3)	lqs(58) hqs(40) gr(2)
p86	28	(5) 10-31 (51)	(887) 1041-1223 (1259)	(23.7) 24.1-24.6 (25.5)	(3.2) 4.5-5.5 (7.5)	lqs(36) hqs(32) al(21)
p87	72	(2) 65-307 (567)	(869) 995-1105 (1257)	(25.2) 26.7-27.5 (29)	(1.6) 2.2-4.9 (5.9)	lqs(50) hqs(26) mf(17)
p88	74	(117) 205-416 (680)	(821) 853-921 (1064)	(25.3) 27.2-28.3 (29.2)	(0.6) 1.2-1.7 (2)	hqs(57) lqs(42) al(1)
p89	91	(9) 113-308 (862)	(846) 1027-1088 (1241)	(22.5) 24.1-24.8 (25.7)	(-0.6) 2.2-3.7 (5.4)	lqs(44) hqs(40) gr(8) va(8)
p90	90	(3) 40-166 (404)	(929) 1040-1120 (1235)	(23.7) 24.1-24.7 (26.3)	(2) 3.5-4.5 (5.5)	lqs(62) gr(24) hqs(6)
p91	73	(25) 246-431 (804)	(891) 981-1061 (1153)	(22.2) 23.5-24.7 (25.5)	(-0.3) 1.5-2.5 (4.6)	lqs(52) hqs(36) gr(10)
p95	54	(7) 132-340 (599)	(947) 1119-1210 (1543)	(24.1) 24.8-25.7 (27.1)	(1.8) 3.9-5 (6.5)	hqs(67) lqs(26) gr(7)
p98	48	(43) 480-805 (1075)	(908) 1032-1097 (1188)	(22) 23.2-24.2 (25.2)	(-1.2) 0-1.6 (3.7)	lqs(40) hqs(27) gr(21)
p99	87	(2) 33-225 (461)	(1022) 1266-1426 (1673)	(23.7) 24.7-25.3 (26.7)	(3.7) 5.1-6.5 (8.1)	lqs(44) hqs(42) vb(8)
p100	33	(199) 352-452 (693)	(1000) 1419-1578 (1845)	(23.7) 24.3-25.5 (26.3)	(2.5) 3.9-4.3 (5.1)	hqs(42) lqs(42) vb(15)
p102	83	(37) 208-490 (700)	(810) 892-1065 (1475)	(24.5) 26-27.2 (28.7)	(0.8) 1.3-2.5 (6.4)	hqs(89) lqs(7)
p103	30	(6) 59-135 (555)	(824) 1117-1240 (1266)	(24) 24.3-25.5 (27)	(2) 4.5-5.4 (6)	lqs(57) hqs(37) al(3) gr(3)
p104	88	(4) 31-99 (338)	(975) 1174-1246 (1289)	(23.6) 24.2-24.7 (26.7)	(2.2) 4.9-5.5 (6.1)	lqs(64) hqs(32) gr(5)
p105	28	(0) 3-7 (38)	(837) 999-1241 (1293)	(23.7) 24.6-25.4 (27.7)	(4.1) 4.8-7.4 (7.9)	al(34) ma(24) hqs(21)
p106	32	(1) 2-6 (107)	(841) 894-1165 (1286)	(22.8) 24.5-25.6 (27.7)	(2.7) 4.2-6.8 (8.1)	ma(33) al(20) lqs(17)
p107	35	(2) 4-7 (206)	(837) 906-1227 (1341)	(21.7) 24.5-24.8 (26.6)	(1.5) 3.5-7 (8.3)	ma(49) hqs(23) al(17)
p109	30	(0) 1-3 (5)	(840) 842-1121 (1312)	(24) 24.5-25.7 (27.6)	(3.5) 3.7-6.6 (8.1)	ma(79) ae(9) hqs(6)
p110	103	(4) 60-321 (479)	(969) 1272-1582 (1922)	(23.7) 24.6-25.7 (26.7)	(3.7) 4.8-5.9 (7.9)	hqs(41) lqs(40) vb(16)
p111	55	(5) 51-181 (332)	(804) 1209-1440 (1817)	(24.2) 24.8-25.6 (28.7)	(2) 5.5-7 (8)	hqs(44) vb(27) lqs(16)
p112	62	(31) 124-279 (551)	(996) 1392-1723 (1978)	(23.2) 24.5-25.1 (26.3)	(2.2) 5.1-6.5 (7.9)	hqs(52) vb(32) lqs(11)
p113	147	(10) 92-364 (594)	(909) 1079-1514 (1931)	(23.2) 24.3-25.3 (28.3)	(2) 3.1-5.3 (6.6)	hqs(47) lqs(43) vb(7)
p114	32	(18) 352-671 (982)	(823) 896-1103 (1264)	(22.8) 25.2-27.1 (28.8)	(0.8) 1-1.7 (5.1)	hqs(81) lqs(9)
p116	36	(8) 137-531 (898)	(797) 973-1070 (1719)	(23.2) 23.7-25.2 (26.5)	(0) 1.8-3.9 (5.5)	hqs(33) gr(28) lqs(28)
p117	134	(9) 82-357 (762)	(898) 1213-1375 (1610)	(23.7) 24.3-25.2 (28.1)	(1.2) 4-6 (8.3)	hqs(75) mf(16) lqs(8)
p120	8	(661) 939-1030 (1057)	(997) 1075-1137 (1161)	(22.7) 23.1-23.5 (25.6)	(0) 0.3-0.5 (1)	hqs(88) lqs(13)
p121	4	(1125) 1143-1153 (1158)	(1030) 1039-1048 (1048)	(22.3) 22.5-22.6 (22.7)	(-0.6) -0.5--0.5 (-0.5)	hqs(75) lqs(25)

Map Unit	n	Elevation (metres above sea level)	Average Annual Rainfall (mm)	Maximum Temp. of Warmest Period (degC)	Minimum Temp. of Coldest Period (degC)	Soil Landscape Lithology (% frequency)
p122	41	(4) 84-641 (755)	(921) 1097-1227 (1370)	(23.7) 24.2-25 (26.2)	(1.5) 2-6 (8)	hqs(90) lqs(5) ae(2) gr(2)
p124	25	(591) 850-1050 (1137)	(988) 1144-1270 (1357)	(22.2) 22.7-23.7 (25.6)	(0) 0.6-1 (1.5)	hqs(100)
p125	4	(688) 704-729 (751)	(951) 966-1029 (1060)	(24.2) 24.4-24.8 (25.2)	(1.2) 1.3-1.4 (1.5)	hqs(100)
p126	15	(14) 56-345 (661)	(940) 1258-1340 (1447)	(23.7) 24.5-25.2 (25.8)	(1.7) 4.2-7.5 (8.1)	hqs(87) mf(13)
p127	11	(23) 45-73 (90)	(1240) 1278-1434 (1438)	(23.7) 23.7-25.2 (25.3)	(6.5) 6.9-8.1 (8.3)	hqs(100)
p129	77	(8) 75-375 (595)	(1039) 1314-1456 (1729)	(23.7) 23.8-24.8 (26.5)	(3) 3.9-7.9 (8.3)	hqs(81) al(16) ae(3)
p130	36	(27) 434-641 (1030)	(861) 1257-1481 (1851)	(22.6) 24-24.7 (26.2)	(0.8) 1.9-3.8 (8)	hqs(75) al(25)
p131	317	(35) 151-404 (850)	(856) 1063-1282 (1658)	(23.7) 25.1-26.7 (28.2)	(0.8) 3.5-5 (7.9)	hqs(77) mf(20) al(2) lqs(2)
p136	50	(367) 704-970 (1052)	(840) 1164-1316 (1377)	(22.3) 23-24.8 (26.5)	(0.6) 1-1.2 (2.2)	hqs(84) mf(8) al(4)
p139	42	(10) 60-78 (141)	(1209) 1305-1446 (1468)	(23.6) 23.7-24.3 (25.5)	(6.5) 7.4-8.3 (8.3)	hqs(64) ae(36)
p140	127	(1) 103-292 (584)	(1023) 1139-1339 (1535)	(24.2) 24.8-25.7 (27)	(2.9) 4.5-5.5 (7.5)	hqs(95) al(2) lqs(2) mf(2)
p141	29	(469) 551-609 (1054)	(1128) 1238-1864 (2012)	(22) 23.5-24 (25)	(-0.3) 2.7-4 (4.1)	hqs(97) al(3)
p142	150	(0) 77-311 (647)	(847) 903-1090 (1455)	(24.6) 26.2-27.2 (28.7)	(1.2) 2.2-4.8 (6.4)	hqs(82) mf(9) lqs(8)
p143	58	(73) 153-211 (434)	(1089) 1261-1312 (1561)	(24.2) 25.1-25.8 (26.8)	(4) 4.7-5.5 (6)	hqs(69) mf(17) lqs(14)
p144	123	(194) 470-657 (967)	(796) 856-939 (1380)	(23.3) 25.4-26.2 (28)	(0.4) 1.2-1.7 (2.9)	hqs(83) mf(9) lqs(8)
p146	213	(1) 110-253 (505)	(845) 902-1011 (1127)	(25.6) 26.7-27.7 (28.8)	(1.5) 2.2-4.1 (5.5)	hqs(49) mf(40) lqs(11)
p148	87	(8) 111-590 (756)	(870) 1107-1217 (1685)	(23.7) 24.9-26 (27)	(1.2) 2.2-5.3 (7.3)	hqs(79) lqs(16)
p149	19	(565) 639-746 (972)	(752) 880-991 (1170)	(23.8) 24.5-25.7 (26)	(-0.3) 1.2-1.6 (2)	hqs(79) lqs(11) al(5) vb(5)
p153	10	(8) 59-155 (178)	(860) 884-1145 (1258)	(26.2) 26.7-28.3 (29.1)	(3.2) 4.3-4.5 (5)	lqs(50) hqs(30) al(10) mf(10)
p168	51	(245) 575-679 (977)	(823) 1094-1389 (1660)	(23.1) 24.2-25.7 (27)	(0.8) 1.6-2.9 (5)	hqs(49) lqs(29) vb(16)
p202	14	(127) 157-199 (440)	(773) 819-848 (927)	(27.2) 28.1-28.8 (29.2)	(1.2) 1.7-2 (2)	lqs(86) hqs(14)
p210	31	(2) 6-24 (156)	(958) 1310-1339 (1416)	(24.1) 24.3-24.8 (25.6)	(4.3) 7.6-8.1 (8.1)	lqs(42) ae(35) hqs(13)
p219	4	(580) 597-646 (647)	(753) 753-755 (756)	(26.6) 26.6-26.9 (27.1)	(0.5) 0.5-0.6 (0.6)	li(100)
p220	57	(600) 759-1043 (1139)	(625) 818-908 (1124)	(21.3) 22.7-24.6 (26.1)	(-1.8) -1.5--0.8 (0.1)	gr(61) lqs(11) va(11) vb(11)
p239	2	(30) 31-31 (31)	(830) 830-830 (830)	(29.1) 29.1-29.1 (29.1)	(3.4) 3.4-3.4 (3.4)	ae(100)
p244	77	(150) 520-689 (1076)	(818) 888-990 (1130)	(22.7) 25.3-26.6 (28.8)	(0.3) 0.8-1.3 (2)	hqs(53) lqs(39) mf(5)
p246	20	(39) 73-176 (620)	(869) 992-1066 (1182)	(25.5) 26.2-26.8 (27.2)	(1.6) 4.5-5.4 (5.6)	lqs(55) hqs(45)
p248	16	(50) 263-717 (792)	(917) 1004-1058 (1240)	(23.7) 24.6-25.1 (25.3)	(0.8) 1.2-3 (5.1)	lqs(56) hqs(38) gr(6)
p266	15	(5) 692-770 (859)	(946) 1102-1276 (1344)	(23.5) 23.8-24.2 (24.5)	(1.3) 1.7-2.2 (4.8)	vb(47) va(27) lqs(20)
p268	4	(588) 600-628 (646)	(886) 1006-1071 (1084)	(24.7) 24.8-25.1 (25.3)	(2) 2.2-2.4 (2.4)	lqs(75) mf(25)
p314	4	(465) 566-606 (615)	(1571) 1794-2004 (2004)	(23) 23-23.5 (24.2)	(3.7) 3.7-4 (4.1)	hqs(100)
p317	69	(353) 577-808 (1066)	(872) 1020-1150 (1392)	(20.2) 22.6-24.2 (25.1)	(-1.1) 0.1-1.1 (2.7)	hqs(43) gr(35) lqs(17)
p338	135	(321) 901-1106 (1374)	(693) 919-1059 (1168)	(20.3) 22.1-23.6 (24.7)	(-2.4) -1.6--1 (1.7)	gr(67) lqs(17) hqs(7)
p343	12	(204) 305-551 (625)	(826) 860-902 (923)	(24.6) 25.2-26.1 (26.2)	(-0.1) 0.4-1.3 (1.8)	gr(100)
p420	24	(239) 700-923 (1050)	(587) 796-904 (950)	(23.1) 24.6-25.5 (26.8)	(-1.5) -0.4-0.6 (1.2)	gr(75) lqs(17) ae(8)
p434	15	(2) 8-19 (26)	(943) 1004-1041 (1243)	(23.7) 23.7-23.8 (24.6)	(4.6) 4.9-5 (6)	lqs(40) ma(27) gr(20)
p502	25	(19) 23-39 (320)	(802) 817-869 (935)	(23.7) 27.3-28.7 (29)	(2) 3.5-4.6 (4.8)	al(52) lqs(24) mf(12)
p509	45	(0) 0-3 (58)	(837) 949-976 (1313)	(23.8) 24.3-24.6 (26.5)	(3.7) 3.9-4.5 (8.1)	ma(46) water(28) lqs(13)

Map Unit	n	Elevation (metres above sea level)	Average Annual Rainfall (mm)	Maximum Temp. of Warmest Period (degC)	Minimum Temp. of Coldest Period (degC)	Soil Landscape Lithology (% frequency)
p514	9	(61) 174-280 (304)	(813) 823-859 (878)	(26.5) 26.7-27.6 (28.7)	(1.7) 2-2.2 (3.7)	lqs(100)
p516	19	(605) 697-756 (796)	(1281) 1563-1633 (1763)	(23.2) 23.3-23.8 (24.2)	(2) 2.5-2.8 (3.2)	vb(79) lqs(21)
p520	35	(513) 604-812 (1231)	(580) 697-851 (984)	(21.7) 24.7-26.2 (27.1)	(-1.6) -0.5-0.8 (1.7)	lqs(37) al(20) gr(14) va(14)
p599	8	(44) 50-74 (90)	(1092) 1281-1286 (1294)	(25.7) 26-26.3 (27.1)	(4.8) 5.3-5.6 (5.6)	lqs(88) hqs(13)

For Maps and Appendices see accompanying CD

Appendix 1: Map Unit Habitat Characteristics

Appendix 2: Index to Map Unit Descriptions

Appendix 3: Descriptions of Map Units

Appendix 4: Survey data collated for classification

Appendix 5: Coverages used in API compilation

Appendix 6: Details of remote imagery used to upgrade and enhance interpretations of contemporary native vegetation cover

Information for authors

Cunninghamia: **a journal of plant ecology for eastern Australia** publishes original research papers on all aspects of plant ecology with particular emphasis on the vegetation and flora of eastern Australia. Descriptive, experimental and historical studies of plant communities, populations, individuals, their interactions with other organisms and their management are acceptable. Acceptance is the responsibility of an editorial committee chaired by the Scientific Editor. All papers are peer-reviewed.

Cunninghamia is published twice a year by the Royal Botanic Gardens and Domain Trust.

Two copies of the manuscript should be submitted along with originals of photographs and figures. Please supply full contact details for main author.

Formatting

- The title should be explicit and descriptive of the content; a short running head and an abstract should be included.
- Check most recent issue for format. *The Macquarie Dictionary*, latest edition, and the *Style Manual for Authors, Editors and Printers*, latest edition, should be consulted for spelling, abbreviations, units and other conventions. Genera should be spelt out in full throughout the text.
- References in the text should be made by giving the author's name with the year of publication in parentheses. For reference list at end of paper see papers in the latest issue for style. Titles of journals should be given in full.

Supply of Artwork

- Captions and scale bars for figures should be checked against the artwork supplied for consistency. If scale bars or lettering need to be added, they should be clearly marked on a photocopy of the artwork.
- Line Art @ 1200 dpi, resolution in eps or tiff format please. Authors wishing to submit other types of files will need to contact the Editor.
- Greyscale Art @ 300 dpi resolution in eps or tiff format please. Authors wishing to submit other types of files will need to contact the Editor.
- Files from ArcView 3.2 are acceptable if exported from the layout as Postscript New (eps) at a minimum resolution of 720 dpi. This must be specified in the options box.
- At the above resolutions, graphic file size will usually exceed 1.2 Mb and therefore will not transport via email or on a floppy disk. Please supply graphics either on a 100 Mb zip disk or burnt to 650 Mb CD. Macintosh compatible please.
- Graphics embedded in Microsoft Word, Excel and Power Point will not be accepted. Items should be saved in the graphic formats tiff and eps as for Line art and Greyscale art.

Artwork supplied as hard copy only

- Artwork supplied should be no larger than A4 (21 cm wide). Any larger images should be brought to the attention of Scientific Editor to see if they need to be outsourced or reduced.
- Hard copy Artwork should be complete and legible as no changes to hard copy artwork can be made post scanning. Any images requiring special treatment (e.g. old maps) should be brought to the attention of the Scientific Editor prior to acceptance of the paper.

Tables

- Tables should preferably be portrait rather than landscape shape i.e. taller rather than wider. Column headings should be brief. Each table must be referred to in the text and its approximate position should be indicated. Please remember that tables need to fit into the journal page size.

Fold-up Maps

- Authors wishing to submit large or complex maps should discuss proposals with the Scientific Editor.

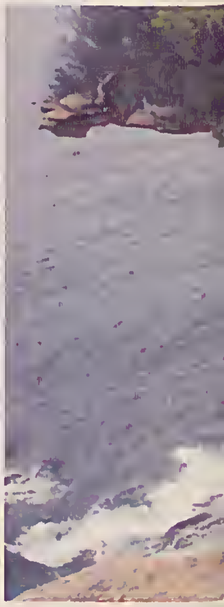
M.G. Tozer, K. Turner, D.A. Keith, D. Tindall, C. Pennay,
C. Simpson, B. MacKenzie, P. Beukers and S. Cox
Native vegetation of southeast NSW:
a revised classification and map for the
coast and eastern tablelands
Cunninghamia: a journal of
plant ecology for eastern Australia
(2010) Volume 11(3)
Botanic Gardens Trust,
Department of Environment,
Climate Change & Water (NSW)

CD to accompany Tozer et al. Native Vegetation of Southeast NSW: a revised classification and map for the coast and eastern tablelands

Cunninghamia

A journal of plant ecology for eastern Australia

Volume 11(3): 277–406 • 2010



SHORT COMMUNICATIONS

Whipcord plants: a comparison of south-eastern Australia with New Zealand
R.F. Parsons 277

Recent ecological observations on growth rates and seed production in *Isopogon prostratus* (Proteaceae), a little-known prostrate shrub from south-eastern NSW and Victoria
Doug Benson and Lotte von Richter 283

RESEARCH PAPERS

Waratah theft in Brisbane Water National Park - An analysis of the blue paint poaching reduction program
Doug Beckers and Catherine A. Offord 287

Coastal sandplain vegetation at Brisbane Water and Broken Bay - reconstructing the past to plan for the future
Robert Payne, Ross Wellington and Michael Somerville 295

Biomass and floristic patterns in the ground layer vegetation of box-gum grassy eucalypt woodland in Goorooyarroo and Mulligans Flat Nature Reserves, Australian Capital Territory.
S. McIntyre, J. Stol, J. Harvey, A. O. Nicholls, M. Campbell, A. Reid, A. D. Manning and D. Lindenmayer 319

Native vegetation of southeast NSW: a revised classification and map for the coast and eastern tablelands
M.G. Tozer, K. Turner, D.A. Keith, D. Tindall, C. Pennay, C.Simpson, B. MacKenzie, P. Beukers and S. Cox 359